

The Pennsylvania State University

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**THE RELATIONSHIP BETWEEN
WELL-STRUCTURED AND ILL-STRUCTURED
PROBLEM SOLVING IN MULTIMEDIA SIMULATION**

A Thesis in

Instructional Systems

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ABSTRACT

Problem solving, especially complicated ill-structured problem solving, has been a major concern in education. Research of the past decade provides qualitative ways of viewing the solving processes of ill-structured problems. Sinnott, Voss & Post, and Jonassen suggested that ill-structured problem solving has to support new, more qualitative, components than those for solving well-structured problems.

This study set forth to test the theory that the problem-solving skills used for well-structured problems are necessary but not sufficient for solving ill-structured problems in the context of an open-ended, multimedia problem-solving environment. Two sets of open-ended questions were posed to reflect students' solving skills in well-structured and ill-structured problems involving astronomy contexts.

Additionally, various instruments including domain-specific knowledge, structural knowledge, and justification skills were developed to measure students' necessary cognitive components for solving problems. Finally, inventories such as science attitude, motivation in astronomy, knowledge of cognition, and regulation of cognition were employed to collect the appropriate data of metacognition and non-cognitive variables.

Generalized, judgmental scoring systems were developed using a quantitative index intended to reflect the extent to which subjects possessed solving skills as well as certain cognitive components of well-structured and ill-structured problems. The results of this study verified past research conclusions that well-structured and ill-structured problems require different necessary components for reaching successful solutions.

In overall, cognition, including domain-specific knowledge and structural knowledge, and justification skills were critical components for successful solution in well-structured problem solving. Alternatively, metacognition, non-cognitive variables, justification skills, as well as cognition, were found to be essential components needed to solve ill-structured problems. Implications for science education in a multimedia simulation environment, assessment on problem solving, and problem-solving research are presented.

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CHAPTER 1. INTRODUCTION

Rationale for Investigation

Problem solving, especially complicated everyday problem solving, has been a major concern in education. One major goal for schools is to educate students who are able to experience the richness and excitement of knowledge about the natural world, be aware of difficult real-world problems, and use appropriate processes and principles in making personal decisions (National Science Educational Standard, 1996). In other words, students must learn ill-structured problem-solving skills by experiencing various real life situations in order to make personal decisions. Many of the problems we face in real life are ill-structured, including important social, political, economic, and scientific problems in the world (Sinnott, 1989; Voss, 1989, 1991).

Educators agree on the importance of the role of ill-structured everyday problem-solving skills in school (Helgeson, 1992). They have attempted to put forth considerable effort to enhance students' problem solving using various teaching and learning strategies, and innovative instructional materials, such as multimedia simulation.

However, more alternative suggestions and promising directions for improving ill-structured problem solving are needed. Research efforts must include a further understanding of the nature of ill-structured problem solving as well as a reevaluation of the methods of instruction for creating rich learning environments to promote everyday ill-structured problem solving.

Purpose of the Study

The purpose of this research study is to test the theory that the problem-solving skills used for well-structured problems are necessary but not sufficient for solving ill-structured problems (Brabeck & Wood, 1990; Kitchener & King, 1981; Mines et al., 1990; Wood, 1990; Wood & Games, 1991) and that ill-structured problem solving has to support more qualitatively new components than those for solving well-structured problems (Reitman, 1965). Ill-structured problems are commonly faced in everyday human experience; they have various solutions and has multiple solving processes which can be derived depending on a solver's perception.

Alternatively, problem solving has been one of the dominant fields of research in the study of human information processing over the past three decades. Research has focused on problems that are relatively well-defined or well-structured (Reitman, 1965; Simon, 1973). Well-structured problems are clearly presented with all the information needed at hand and have convergent answers and single solving processes to reach a final solution (Simon, 1978), such as long division, areas of triangles, Ohm's law, and linear equations (Wilson & Cole, 1992). Consequently, theories of problem solving have been largely pervaded by the empirical phenomena of well-structured problems. Furthermore, instruction in problem solving generally emphasizes well-structured problems.

However, educators (Spiro, et al., 1988; Spiro & Jehng, 1990) have attempted to apply traditional theory in teaching complex and ill-structured domains (Wilson & Cole, 1992). They have realized that the traditional theory is not sufficient for enhancing ill-structured problem solving. They argued that a traditional learning environment seldom requires students to solve everyday problems. Furthermore, students are presented with single analogies or discrete procedures and rules which are oversimplified and overgeneralized as compared to those of ill-structured problems (Wilson & Cole, 1992).

Based on this contradiction, it is reasonable to question how the solving skills of well-structured problems are critically different from those of ill-structured problems which are faced by individuals in everyday life (Reitman, 1965). The specific research objectives of this study are: a) to propose ill-structured problem solving requires different essential components than those of well-structured problems, and b) to define in depth the different critical components of well-structured and ill-structured problem solving.

Problem Statement

Although educators agree on the importance of the role of ill-structured everyday problem-solving skills in school (Helgeson, 1992), there is confusion about what defines an ill-structured problem, as well as about the relationship between well-structured and ill-structured problems.

Neisser (1976) equates everyday or real-life problems with ill-defined problems. Some educators believe all everyday human problems are ill-structured problems. Ill-structured problems differ from "ill-defined" problem spaces in that "ill-defined" problems may not allow a clear solution strategy, but may allow single correct answers about which qualified experts would agree (Hayes, 1981; Holyoak, 1990; Sternberg, 1985).

Ill-structured problems can be defined as problems which do not have known solutions. Experts in the domain do not agree regarding whether a particular solution is appropriate, because it has various solutions and solution paths (Jonassen, 1997; Reitman, 1965; Voss, 1988, 1989).

Confusion of Relationship between Well-Structured and Ill-Structured Problems

In addition to the inconsistency of the definition of ill-structured problems, more confusion exists surrounding the relationship between well-structured and ill-structured problems. Simon (1973) insisted that whether a problem is well-structured or ill-structured could only be determined by examining the problem solver, his available knowledge, and the problem to be solved. Depending on an individual's solving ability and knowledge relating to domains, problems may be well-structured or ill-structured. Furthermore, Simon (1973) argued the processes used to solve ill-structured problems can be applied in the same way to solve well-structured problems. In other words, information-processing models that have been applied to the study of relatively well-structured problems are adequate to deal with relatively ill-structured problems.

On the contrary, Reitman (1965) argued that ill-structured problems are the central point of largest percentage of human energies, yield larger individual variability in solutions, and produce less agreement on the acceptability of solutions when compared to well-structured problems. In Reitman's perspective, since ill-structured domains are less definable, and more conditional and problematic, solvers have to combine or recombine schemas in response to the requirements of each particular situation, rather than merely retrieve a schema from memory (Wilson & Cole, 1992). This nature of ill-structured domains is difficult to capture using traditional theory.

To summarize Reitman's theory, ill-structured problem solving has obviously engaged more complicated processes than those of well-structured problem solving. Information-processing models are not sufficient to explain ill-structured problem-solving processes.

Research on ill-structured everyday problem solving (Sinnott, 1989; Voss & Post, 1988; Voss, 1991; Wood, 1994) has supported Reitman's idea that well-structured and ill-structured problems require different components to reach solutions. Solving ill-structured problems requires components such as content knowledge, structural knowledge, domain-

specific strategy, and general searching strategy, which are used to solve well-structured problems as well as those “beyond the purely cognitive” such as value/belief/attitude, evaluation/monitoring/planning, and justification skills (Sinnott, 1989). Additionally, investigators examined solution processes in solving ill-structured problems and found there are too many steps that appear to be unexplained using well-structured problem-solving processes (Sinnott, 1989; Voss & Post, 1988; Voss et al., 1991).

Limitations of Research Studies in Ill-Structured Problems

Although many studies (Sinnott, 1989; Voss & Post, 1988; Wood, 1994) have concluded that well-structured and ill-structured problem solving use different solving processes, their research lacks generalizability to other tasks. As shown in Table 1.1, the current research of ill-structured problems has concentrated on qualitative research methodology using a think-aloud protocol approach. The sample size was in the small range, using from 3 to 24 subjects who were mainly adults or college students.

Moreover, most research studies regarding ill-structured problems described the solving processes of one particular domain rather than comparing two different solving processes in the same domain (Herbert & Dionne, 1993; Korpi, 1991; Voss, 1988). Some researchers (Brabeck & Wood, 1990; Mines et al., 1991; Wood & Games, 1991) have tried to compare solving ability between two problem types. However, they used Critical Thinking for well-structured problem solving and Reflective Judgment for ill-structured problem solving, rather than measuring solving ability of two different problems in the same domain.

The holes in past research pose at least three questions: it is difficult to clarify why well-structured problem-solving skills are not sufficient to solve ill-structured problems in the same domain; what is the relationship between well-structured and ill-structured problem solving in the same domain; and whether the results can be generalized with regard to young students, such as high school students. Because of this weak evidence, more research is necessary to determine why well-structured problem-solving skills are insufficient for solving ill-structured problems in the same domain.

Table 1. 1

Examples of Studies in Ill-Structured Problem Solving

Author	Problem Domains	Research Method	Subjects
Herbert & Dionne, 1993.	Several practical or technical problems, and everyday problems.	TA	24 adults
Korpi, 1991.	Design instructional material.	TA	3 adults
Sinnott, 1989.	Various everyday problems.	TA	3 adults
	WPS		
Brabeck & Wood, 1990; Kitchener and King, 1981; Mines et al., 1990;	Critical Thinking measured by WGCT Verbal ability measured by TCMT.	TA	College students
Wood, 1990; Wood & Games, 1991.	IPS Reflective Judgment skills measured by RJI.		
Voss, 1988; Voss, Lawrence, & Engle, 1991; Voss & Post, 1988.	Social science problems (e.g., political science problems, international relations).	TA	3 - 6 adults

Note. TA = Think-Aloud Protocol, WPS = Well-Structured Problems, IPS = Ill-Structured Problems, WGCT = Watson-Glaser Critical Thinking, TCMT = Terman's Concept Mastery Test, and RJI = Reflective Judgment Interview.

Significance of the Problem

In the science education community, a wide variety of terminology has been used to describe the dynamic solving processes in science phenomena, including science discovery, scientific method, scientific thinking, critical thinking, inquiry skills, and science processes (Champagne & Klopfer, 1981a).

Specifically, many science educators have attempted to facilitate the problem solving in science using the terminology related to science processes (Gagne, 1970; National Science Education Standard, 1996; Simon, 1981). Gagne (1970) clearly explained science processes that can be categorized under the general categories of observing, classifying, measuring, using space-time relations, using numbers, communicating, and inferring. Additionally, the National Science Education Standard (NSES) stated that science processes can be defined as processes in which "students describe objects and events, ask questions,

acquire knowledge, construct explanations of natural phenomena, test those explanations in many different ways, and communicate their ideas to others” (1996, p 21).

Based on the above definition of science processes, the science processes can be explained in terms that have been used to explain the processes of problem solving (Simon, 1981). It has much in common with problem-solving processes.

As shown in Table 1.2, although many educators (Gane, 1970; NSES, 1996; Simon, 1981) emphasized science processes as problem solving in science, they did not make distinction between well-structured and ill-structured science processes. Additionally, science educators have put forth considerable effort to enhance students’ science processes using various teaching and learning strategies such as scientific inquiry under the same category of well-structured and ill-structured science problems.

Table 1. 2

Comparisons of Problem Solving, Science Processes and Scientific Inquiry

Problem-Solving Processes	Science Processes	Scientific Inquiry
<ul style="list-style-type: none"> • Defining Problem 	<ul style="list-style-type: none"> • Describing objects and events • Asking questions 	<ul style="list-style-type: none"> • Observing • Posing questions
<ul style="list-style-type: none"> • Searching information • Selecting information • Organizing selected information 	<ul style="list-style-type: none"> • Acquiring knowledge • Constructing explanations of natural phenomena relationship between ideas 	<ul style="list-style-type: none"> • Examining books and other sources of information to see what is already known
<ul style="list-style-type: none"> • Developing justification for selection 	<ul style="list-style-type: none"> • Describing rationale for formulating these relationship between ideas 	<ul style="list-style-type: none"> • Reviewing what is already known in light of experimental evidence
<ul style="list-style-type: none"> • Generating Solutions 	<ul style="list-style-type: none"> • Testing explanations in various ways 	<ul style="list-style-type: none"> • Planning investigation • Using tools to gather, analyze, and interpret data
<ul style="list-style-type: none"> • Suggesting potential solutions 	<ul style="list-style-type: none"> • Predicting other natural phenomena, and ways to apply them to many events 	<ul style="list-style-type: none"> • Proposing answers, explanations and predictions
<ul style="list-style-type: none"> • Developing justification for solution 	<ul style="list-style-type: none"> • Communicating their ideas to others 	<ul style="list-style-type: none"> • Communicating results

Scientific inquiry is emphasized as one of the primary educational strategies to be used to promote students' understanding of science processes (NSES, 1996, p 23) (see Table 1.2). The scientific inquiry is applied to facilitate learners' science processes in the both well-structured and ill-structured science problems in spite of the existence of clear different solving processes and components between two type of problems.

Although NSES set ill-structured everyday problem solving as a goal for science education, NSES described teaching standards, assessment in science education, and content standards under the same principles without categorizing separately well-structured and ill-structured problem solving.

This investigation intends to propose that ill-structured science problems are different in solving processes and components as compared to those of well-structured science problems. Therefore, science educators must develop different teaching and learning strategies, as well as different assessment depending on a type of problems in order to promote students' ill-structured science problem solving.

This study will attempt to raise the level of awareness of the relationship between well-structured and ill-structured problem-solving skills. It will also provide educators with guidance for effective design, development, and evaluation methods to facilitate students' problem-solving skills, depending on educational goals and the nature of problems in their classroom.

Additionally, using 9th-grade high school students as subjects, the research will show the relationship between two different sets of problem-solving skills in science. It will guide the future development of effective teaching and learning environments to facilitate high school students' ill-structured problem solving in science. Finally, since the integration of research will be made with a larger sample and replicable method than those previously used (Brabeck & Wood, 1990; Chi, 1988; Voss, 1988, 1989), the conclusions from this study, with respect to the questions stated, may support stronger generalizations than past research.

In order to understand the nature of ill-structured problem solving, essential components of solving ill-structured problems must be defined and described based on their solving processes. In this manner, the essential components of ill-structured problem solving can be compared to those of well-structured problem solving. Such a comparison allows us to see which components should be emphasized for teaching ill-structured problem solving.

Conclusions derived from the accumulation of past research will provide the data to define necessary components, including cognition, metacognition, non-cognitive variables, and justification skills for solving both well-structured and ill-structured problems (Bransford, 1994; Chi, 1988; Sinnott, 1992; Voss & Post, 1989; Wood, 1993). The components will be described in depth in the literature review section. Next, these components will be correlated with both well-structured and ill-structured problem-solving scores in science, to infer the most important components for each type of problem-solving process. Additionally, the results will be compared to analyze the differential components of well-structured and ill-structured problem solving within the same domain. Such analysis enhances the interpretation of essential components in each problem-solving skills as well as the critically different components between well-structured and ill-structured problem solving.

Components of Well-Structured Problem Solving

First, this study will investigate the relationship between students' well-structured problem-solving scores and components for solving well-structured problems. To solve well-structured problems, an individual commonly follows four solving processes. The processes include (a) finding out exactly what the problem is, (b) finding appropriate information from individual's memory, or applying domain-specific or general searching strategies to solve the problem, (c) selecting the best solution by anticipating the logical consequences of each, and (d) implementing the solution and evaluating it to see if it solved the problem (Bransford & Stein, 1983; Newell & Simon, 1972).

Domain-specific knowledge plays an important role in well-structured problem solving (Glaser, 1989). However, domain-specific knowledge is not enough to solve well-structured problems. The knowledge has to be organized or integrated meaningfully in a domain to successfully solve well-structured problems. It is proposed here that structural knowledge may strongly influence well-structured problem-solving skills. Generally, cognition is more essential than other components such as metacognition including general searching strategies, planning, monitoring, and evaluating, or non-cognitive variables including value, belief, and attitude in solving well-structured problems.

Components of Ill-Structured Problem Solving

Secondly, this study will investigate the relationship between students' ill-structured problem-solving scores and components for solving ill-structured problems. In solving ill-structured problems, solving processes include (a) recognizing that there is a problem, (b) finding out exactly what the problem is, (c) searching and selecting some information about it, (d) developing justification by identifying alternative perspectives, (e) organizing obtained information to fit a new problem situation, (f) generating some possible solutions, (g) deciding on the best solution by the solver's perception of problem constraints, and (h) implementing the solution and evaluating it by developing arguments and articulating personal belief or value (Voss, 1988).

Based on the analysis of ill-structured problem-solving processes, cognition, metacognition, ability to develop justification, and non-cognitive variables are important to solve ill-structured problems. As in well-structured problem solving, structural knowledge is more important than domain-specific knowledge.

From well-structured and ill-structured problem-solving processes, it can be summarized that the following components are necessary: (a) cognition including domain-specific knowledge and structural knowledge; (b) metacognition, including general searching strategies, planning, monitoring, and evaluating; (c) non-cognitive variables, including value, belief, attitude, and motivation; (d) justification skills such as ability to develop argumentation.

Research Questions

This study focuses primarily on components necessary for solving well-structured and ill-structured problems, in order to examine the relationship between well-structured and ill-structured problem solving. The main questions include what components are needed to solve each problem type and how the required components differ between the two problem types. Thus, the research questions under the study become:

Question 1. What different components are required in solving ill-structured problems as compared to those of well-structured problems solving?

Question 2. Do well-structured problems require (a) cognition, (b) metacognition, (c) non-cognitive variables, and (d) justification skills as essential solving components?

Question 3. Do ill-structured problems require (a) cognition, (b) metacognition, (c) non-cognitive variables, and (d) justification skills as essential solving components?

In this study, these research questions will be investigated in the context of an open-ended, multimedia problem-solving environment. The National Aeronautics and Space Administration (NASA) Classroom of the Future (COTF) organization has developed a multimedia curriculum supplement software program entitled, *Astronomy Village® (AV): Investigating the Universe*. This program is for high school science classrooms to teach the processes of scientific inquiry as well as astronomical and mathematical concepts. Ten investigations cover a broad cross-section of current research areas in astronomy. Each investigation encourages students to participate in scientific inquiry as a member of a cooperative learning group.

AV, a multimedia software program will be used as an instructional environment. During 4 weeks' science classes, the program presents a virtual mountain-top observatory interface from which students investigate contemporary problems in astronomy. During the work with *AV*, students are encouraged by their “virtual” mentors to conduct an activity for each of the phases of scientific research.

CHAPTER 2. LITERATURE REVIEW

The literature review focuses in depth on ill-structured problems, their solving processes as well as their solving components. At first, well-structured problems, their solving processes, and their components are briefly described. In a similar manner, ill-structured problems and their solving processes are defined and explained, based on existing research studies. The necessary components for solving ill-structured problems are described from an analysis of the solving processes. Finally, the two problem types are compared on three levels: the nature of the problems, their solving processes, and the components necessary for solving each problem. This comparison is necessary to illustrate the differences between well-structured and ill-structured problems, and to assist in building the research design. The review explains the hypotheses of the current study and concludes with the need for the proposed study.

Well-Structured Problems

Well-structured problems include most mathematics and mathematics-related problems (e.g., solving algebra), and physics problems such as those found in undergraduate textbooks. They have a single correct, convergent answer to reach a satisfaction in a final solution (Simon 1978) so it requires a relatively small amount of information or constrained knowledge based on material presented in the textbook chapter.

A well-structured problem consists of all elements of the problem including a well-defined initial state, a known goal state, constrained set of logical state, and constraint parameters (Greeno, 1978). Transformation problems may be representative of a well-structured problem. It requires the application of a finite number of concepts, rules, solutions, and principles being studied to a constrained problem situation (Luszcz, 1984). Therefore, the well-structured problem-solving skills can be transferred only to similar types of problems.

Well-structured problems can be solved using various search techniques, such as recall analogical problems, means-ends analysis, decomposing and simplifying, finding sub-goals, and generate or test. The solution process generally has been agreed-upon, and varies only slightly among experts in the particular problem domain. That is, there are only relatively small differences in the problem-related contents and a consensual agreement among experts in the field regarding the established solution (Luszcz, 1984).

Solving Process of Well-Structured Problems

Many researchers (Bransford & Stein, 1984; Chi, 1988; Newell & Simon, 1972) have conducted studies about well-structured problems. Most research in the psychology of problem solving has analyzed problem solving using concepts of information processing (Newell & Simon, 1972), such as the classic General Problem Solving (Newell & Simon, 1972), and IDEAL problem solver (Bransford & Stein, 1984). Information-processing models of problem solving generally specify two sets of thinking processes associated with the problem-solving process: understanding processes and search processes. Based on various problem-solving models, well-structured problem solving is described in three essential processes including a) representing problems, b) searching for solution, and c) implementing a solution.

First, when solvers are faced with a problem, the solvers literally understand a task from the problem statement, which can include the following questions (Voss, et al., 1991): What is the goal? What is an acceptable solution path? and what is the final production supposed to be? After understanding a task, the solvers attempt to represent the problem in terms of the solvers' understanding of the givens, the goal, the underlying structure of the possible solutions, and any problem-solving strategies that can be used to solve this task (Voss, et al., 1991). This is known as a problem space which is constructed by a person's interpretation of the problem.

During the construction of a problem representation, certain features of the problem may activate knowledge in memory. A certain schema for that particular type of problem may then be activated. An activated schema is a cluster of knowledge related to a problem type (Greeno, 1978). The solvers are able to proceed directly to the implementation stage of problem solving and try out the activated solution depending on the representation. The quality of a problem representation directly influences the potential of solving the problem (Hayes, 1981; Newell & Simon, 1972).

If schema activation occurs during the construction of a problem representation, then the solver can proceed directly to the implementation of solution strategies with little search for solution procedures (Chi et al., 1982). This indicates that the representation phase often consists of a pattern-matching procedure. Pattern-matching refers to a situation in which the problem statement is considered in terms of its parameters and the relation between parameters, and these components are matched to a pattern in memory (Voss, 1988). If solvers have previous experience with this type of problem, they are able to perform the

match and, subsequently, provide the solution.

Second, if solvers fail in schema activation during the construction of a problem representation, the solvers have to search for a solution to the problem. In searching for a solution, the solvers are required to include the use of domain-specific strategy, as well as general searching strategies. The domain-specific strategies are specific to their respective domains. In the contrast to domain-specific strategy, the general searching strategies are more general and can be applied across a variety of domains.

The use of some general searching strategies may be constrained by domain-specific knowledge. The solvers choose appropriate searching strategies based on the content of domain as well as the type of a problem. Solvers frequently use a process of means-ends analysis, in which they try out equations that contain one or more of the parameters found in the problem statement, and eventually reach the goal by generating an appropriate sequence of equations (Larkin et al., 1980). These strategies may not guarantee solution, but serve as a guide in the problem-solving process (Mayer, 1983).

Finally, after generating appropriate equations or solutions, solvers attempt to try out the solutions. If the solution is satisfied, the task is over. If it fails, the solver goes back to an earlier stage and attempts to redefine the problem or use another method to solve it.

Summary of Well-Structured Problem-Solving Processes

Well-structured problem-solving processes include a) representing problems by schema activation, b) searching solutions, and c) implementing solutions as show in Figure 2.1. Based on a review of the solving processes of well-structured problems, the components for solving well-structured problems may be summarized as cognition and metacognition, or specifically, knowledge of cognition.

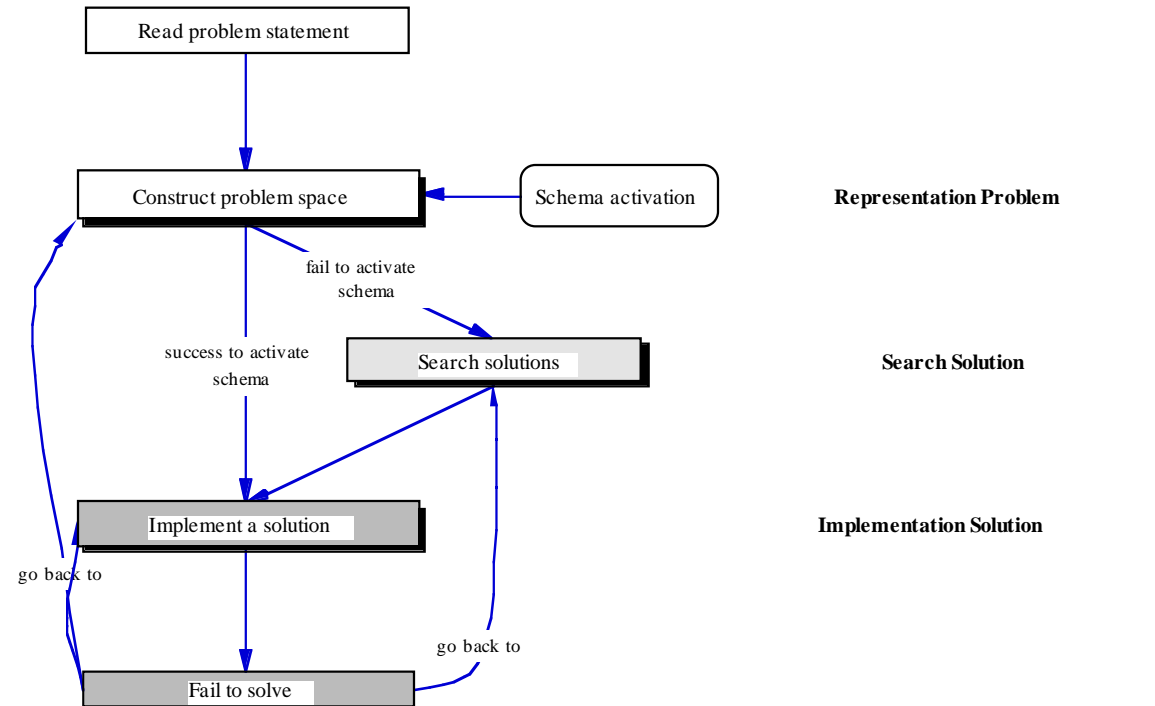


Figure 2.1. Diagram of Well-Structured Problem-Solving Processes

Components for Solving Well-Structured Problems

Cognition

One of critical components of well-structured problem solving is domain-specific knowledge (Glaser, 1984) which includes declarative knowledge and procedural knowledge. Declarative knowledge includes the basic concepts, facts, and principles of a particular subject matter domain (Ryle, 1949). Procedural knowledge in a particular domain is a domain-specific strategy (Ryle, 1949). The domain-specific strategies are specific to their respective domains. For example, in geometry, a strategy for proving that two triangles are congruous is to prove that they are corresponding angles of congruent triangles (Greeno, 1980). In algebra, a useful strategy to solve equations is an isolation strategy, in which the solver isolates the target variable on the left side of the equation and places all the numbers on the right side of the equation (Mayer, 1982). Therefore, domain-specific strategy is directly related to the content of the domain and depend on solvers' content knowledge.

In solving well-structured problems, if learners possess appropriate schematic driven knowledge, the learners can directly solve the problem without searching for a solution using various searching strategies. Solvers are able to work forward immediately by choosing appropriate equations leading to the goal, because they recognize each problem from their previous experience and know which moves are appropriate.

Structural knowledge is a more essential component than domain-specific knowledge. The structural knowledge allows solvers to accurately recall the configuration of a given problem state and immediately to move toward the goal from the givens. Experts, possessing schemes allowing them to distinguish between problem states and their associated moves, may categorize problems according to those schemes (Chi, et al., 1981).

The critical role of structural knowledge can be seen in the solving process of well-structured problems. A problem representation of well-structured problems is a cognitive structure corresponding to a problem which intentionally links the problem to existing knowledge on the basis of solvers' domain-related knowledge and its organization (Greeno, 1978). This process is a continuously constructed schematic network based on various problem components, including the initial state, the desired goal, and the legal problem-solving operators (Chi, et al., 1981). Thus, the representation is enhanced by existing problem schemes that result from a previous experience in solving the particular type of problem.

Many researcher found that structural knowledge is important in solving well-structured problems. For example, Larkin, et al., (1980) have demonstrated that when physics experts are given a problem from a physics textbook, they develop a representation of the problem by analyzing the elements and relations of the problem, sometimes drawing a diagram in the process. Typically, such examination leads to the classification of the problem, and once classified, the problem is solved by applying the appropriate equations (Chi, et al., 1982).

Metacognition

Knowledge of cognition.

If solvers do not have previous experience with a specific type of problem and fail to activate a correct schema from their memory, solvers require general searching strategies that may be applied across a variety of domains. Researchers have found some of strategies assist well-structured problem solving.

Analogy is one of the strategies for helping well-structured problem solving (Jonassen, 1997). Solvers recall analogical problems, for which the solution is known, from their previous experience and apply the analogy to a new problem (Polya, 1957). Gick and Holyoak (1980) found that the analogy assists successful problem solving when students were prompted to think analogical problems.

Means-ends analysis used by General Problem Solving (Ernst & Newell, 1969), involves reducing the differences between the current state and the goal of the problem by applying appropriate problem-solving operators. This strategy is useful whenever the initial and goal states of a problem are fairly well specified (Gick, 1986). However, means-ends analysis hinder schema learning because solvers concentrate merely on eliminating discrepancies between the current state and goal state (Owen & Sweller, 1985; Sweller & Levine, 1982; Sweller, et al., 1983). When the solvers achieve the current goal by applying an operator, they ignore the goal and focus on the new goal instead of reflecting the successful operator at the next process.

In sum, structured knowledge and domain-specific knowledge is a primary component of solving well-structured problems. When solvers do not have appropriate knowledge in a particular domain, they are required to use domain-specific strategies and general searching strategies for searching a path or a solution (Chi, et al., 1982).

Ill-Structured Problems

Ill-structured problems are faced routinely in everyday human experience. In everyday human problems situated in a specific context, the problem descriptions are vague, or the information needed to solve them is not provided in the problem statement (Chi & Glaser, 1985).

In ill-structured problems, the number of goals, which are vaguely defined, must be considered in the problem-solving process. The information available to the decision maker is usually incomplete and inaccurate or ambiguous (Wood, 1993). In these problems, it is uncertain which concepts, rules, and principles are necessary for the solution. There is an inconsistent relationship between concepts, rules, and principles among cases. Case elements are differentially important in different contexts based on the interaction of the elements with each other in a context (Spiro, et al., 1987, 1988).

Solving Process of Ill-Structured Problems

Many researchers have conducted studies to understand ill-structured problem-solving processes, applying a qualitative methodology such as think-aloud protocol. Ill-structured problems may possess multiple solutions, solution paths, or no solution at all (Kitchner, 1983); may possess multiple criteria for evaluation solutions, because there is not universal agreement on the appropriate solution (Voss, 1988); and require solvers to express personal opinions or beliefs about the problem in the process of interpretation (Meacham & Emont, 1989).

In this section, solving processes of ill-structured problems will be described based on the studies of Sinnott (1989) and Voss & Post (1988). They investigated ill-structured problems and explained each process involving ill-structured problem solving using a think-aloud protocol approach. Ill-structured solving processes will be divided into three categories: representation problems, solution processes, and monitor and evaluation based on the two studies.

Sinnott (1989) conducted a longitudinal study with 150 respondents in order to understand ill-structured problems. Based on this study, Sinnott discussed in some depth three respondents' solving processes of ill-structured problems using a think-aloud protocol approach. She created a model of the five main components used in solving

ill-structured problems including a) processes to construct problem space, b) processes to choose and generate solutions, c) monitors, d) memories, and e) noncognitive elements.

In her model, she described two basic sets of thinking processes in solving ill-structured problems, including processes to construct problem space, and processes to choose and generate solutions. She emphasized specific processes to choose and generate solutions. She argued that solvers must select the essence of a problem; then they must select the goal or goals; and finally a solution must be generated and selected among many possible solutions. Since ill-structured problems may have generate a large number of possible goals, Sinnott insisted that the solvers must have a mechanism for selection of the best goal or solution. She found that solvers selected goals that were suitable to the chosen problem essence, as well as goals they knew were reachable, or goals which had specific solution paths.

In sum, Sinnott's model proposed that the solving processes of ill-structured problems engage constructing problem space, and choosing and generating a solution. Monitors, memories, and noncognitive elements are necessary components within the two solving processes.

On the basis of a study of international political science problems, Voss & Post (1988) proposed that problem-solving processes involve a) representation of the problem, b) statement of a solution, and c) evaluation. In their study, the representation problem is an extremely important process for determining the solution of ill-structured problems.

They argued that the representation problem involves processes of examining the concepts and relations of the problem, delineating the causes of the problem and its constraints, and recognizing the divergent perspectives. Once a specific representation is developed, the solution is readily predicted from the representation and is a relatively small component in establishing structure. That is, if the solvers develop a successful representation problem, a particular solution will follow from that representation, and consequently a good solution (Voss, 1988, 1991).

Once alternative options have been identified, Voss & Post found that a solution to the problem may be proposed by alleviating or eliminating these causes. After suggesting solutions, a solution is developed using procedures which implement the solution step by step. The solution that is proposed must be evaluated with respect to its potential positive and negative effects on the solvers' interpretation of the situation, and the prescribed course of action.

Based on the two authors' theories, ill-structured problem solving can be summarized as three processes: a) representation problems, b) solution process, and c) monitor and evaluation. A representation problem is established by constructing a problem space which includes defining problems, searching and selecting information, and developing justification of the selection. The solution process involves generating and selecting solutions. Finally, the monitoring and evaluating process requires assessing the solution by developing justification. The next section will describe in depth these processes.

Representation Problems

When solvers are faced with a given problem situation, they first decide if there is a problem, because the ill-structured problem may not appear directly or may be hidden (Jonassen, 1997).

After determining the existence of a problem in a problem statement, solvers need to determine the nature of the problem (e.g., what is a kind of a problem?). In determining the nature of the problem, the solvers construct a problem space which contains all of the possible states of the problem by examining the possible causes of the problem as well as its constraints (Sinnott, 1989; Voss & Post, 1988). Since an ill-structured problem may have multiple representations or understandings of the problem, determining an appropriate problem space among the competing options is the most important process of an ill-structured problem (Jonassen, 1997).

For constructing problem space, the solvers initiate a search, either internally or externally, to obtain information appropriate to the problem (Voss & Post, 1988). The solvers attempt to find and select critical information from memory drawing on extremely large amounts of information. After the solvers determine sufficient amounts of information have been obtained, they terminate the search immediately. This information enables the solvers to enter the next problem state. The selected information is required to determine how to fit in a new context rather than simply retrieve it from memory in the course of constructing problem space, because ill-structured problems cannot be solved by applying a constrained set of rules (Voss & Post, 1988).

Based on selecting and evaluating information, the solvers may depict the cause of the problem in a problem statement. Since ill-structured problems usually have divergent or alternative solutions, solvers must develop a justification or an argument for supporting the rationale of their selection of a particular cause. So solvers need to construct multiple

problem spaces, instead of constructing a single problem space, for providing evidences of the claims in the representation and development of an argument (Jonassen, 1997). Among competing problem spaces, the solvers must decide which of the schema is closely relevant and useful for solving (Sinnott, 1989).

Solution Processes

Selecting information allows solvers to generate and select a solution. The solvers generate solutions that alleviate the causes, relying on not only a prior knowledge but also on task-unrelated thoughts and emotions (Sinnott, 1989). After generating or developing solutions, solvers select a solution that they think may be reachable, based on their perceptions of problem constraints. The solvers are building their own mental model of the problem to identify and select, or synthesize, a solution based on a representation problem (Jonassen, 1997). The solvers' mental model is able to propose a solution by analyzing possible causes of the problem.

Monitor and Evaluation

A problem-solving process is driven by a problem-solving control structure and an argument or reasoning structure (Voss & Post, 1988). Since a solution process is basically one of rhetoric, it is an important argument or reasoning structure which is subordinated to the problem-solving control structure (Voss & Post, 1988). Therefore, solvers must select a solution by constructing how they came to that decision. In ill-structured problems, since a good solution requires consensual agreement among the community, the solvers must provide the most viable, the most defensible and the most cogent argument to support their preferred solution, and defend it against alternative solutions (Voss & Post, 1988; Jonassen, 1997).

Solvers must continuously evaluate and monitor their solving processes in order to justify their selections and a solution. In developing an argument or reasoning structure, the solution is typically justified by indicating why and how the proposed solution would work, as well as by indicating why the solution may not work (Voss, 1988). What can be done to handle possible shortcomings and objections (Voss, 1988)? If the solution is unsatisfied, a solver may "go back" and "re-present" the problem to find appropriate solutions (Voss, 1991).

In sum, solvers continuously monitor and evaluate their thinking process until

completing the problem solving. During a solving process in ill-structured problems, solvers monitor their own processes, movements from state to state, selecting information and solutions, and emotional reactions (Sinnott, 1989). In addition, solvers evaluate their selection by examining and comparing other alternatives. This monitoring and evaluating process requires a wide variety of memories such as personal histories, emotional memories, problem-related memories, and abstract rules (Sinnott, 1989).

As explained above, the three essential solving processes require various subprocesses in order to link to the next solving process. Jonassen (1997) presented and explained seven important solving processes used in the course of solving ill-structured problems. These can be categorized in three processes as shown in Table 2.1.

Table 2. 1

Ill-Structured Problem-Solving Processes

Voss & Post (1988)	Sinnott (1989)	Jonassen (1997)
<u>Represent problems</u> <ul style="list-style-type: none"> • Examining the concepts and relations of the problem. • Delineating the causes of the problem and its constraints. • Recognizing the divergent perspective. 	<u>Construct of problem spaces</u>	<ul style="list-style-type: none"> • Articulate Problem space and contextual constraints. • Identify and clarify alternative opinions, positions, and perspectives of Stakeholders.
<u>State solution</u>	<u>Choose and generate solutions</u>	<ul style="list-style-type: none"> • Generate possible problem solutions.
<u>Evaluate</u>	<u>Monitor</u>	<ul style="list-style-type: none"> • Assess the viability of alternative solutions by construction arguments and articulating personal beliefs. • Monitor the problem space and solution options. • implement and monitor the solution. • Adapt the solution.

Summary of Ill-Structured Problem-Solving Processes

On the basis of studies of Sinnott and Voss & Post, the dynamic solving processes of ill-structured problems generally involve a) representing problems by searching and selecting information, and supporting justification, b) stating solution by generating and selecting options, and c) supporting justification of the solution by monitoring and evaluating solution processes as shown in Figure 2.2.

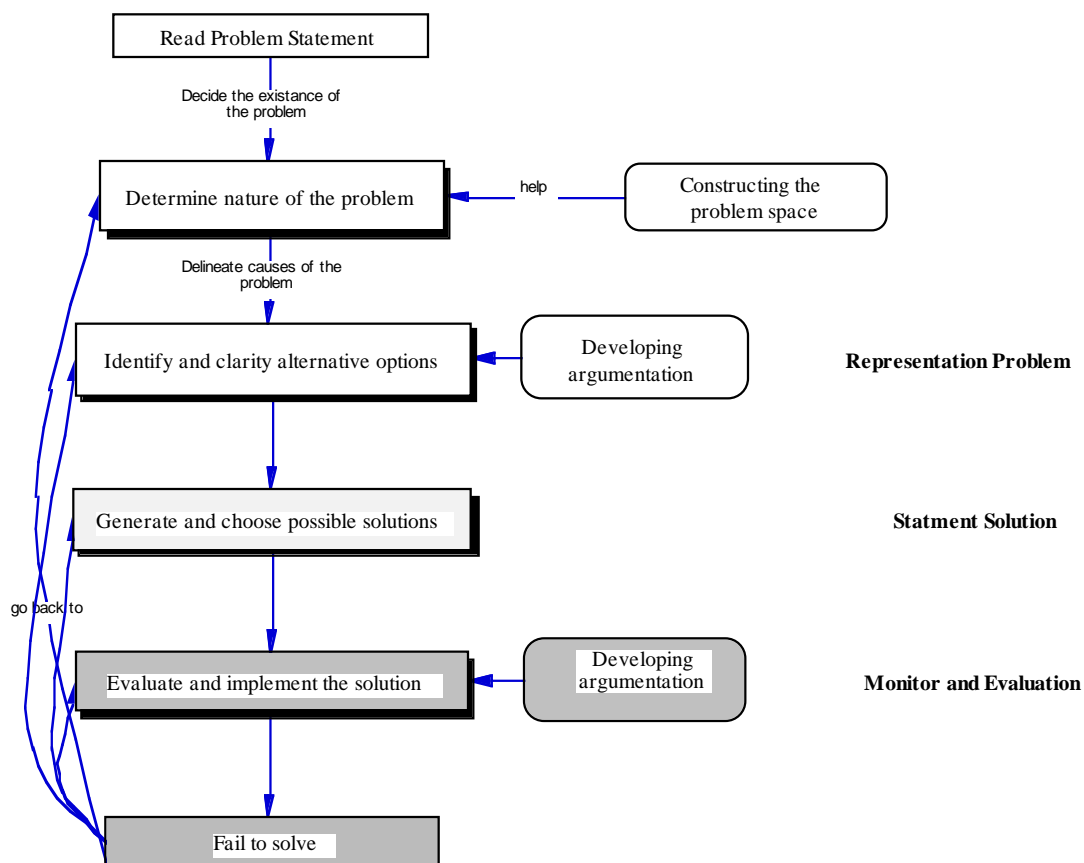


Figure 2.2. Diagram of Ill-Structured Problem-Solving Processes

Based on an analysis of the nature of solving processes, necessary components for solving ill-structured problems can be defined. The following section will describe important components including cognition, metacognition, non-cognitive variables, and justification skills for solving ill-structured problems.

Components of Solving Ill-Structured Problems

Cognition

Well-developed domain-specific knowledge is a primary factor in solving ill-structured problems. Domain-specific knowledge assists a solver in the selection of general operators from among many alternatives and in finding a search path of ill-structured problem solving (Roberts, 1991). Jonassen (1997) argued that although individuals have ability to solve problems, they can not transfer the prior problem-solving skills to other domains without appropriate content knowledge. In addition, Voss, et al., (1991) found that expertise in solving ill-structured problems is highly domain-specific. Better developed domain knowledge may enhance problem-solving ability in any particular domain. If the individual does not have and employ substantial knowledge of the domain in a question, the applications of the methods will lead to inadequate solutions (Voss, et al., 1991).

Although having domain-specific knowledge is, in itself, of critical importance, ill-structured problems cannot be solved by simply finding the information and applying a constrained set of rules. Since the solutions of ill-structured problems depend on situation or context, domain-specific knowledge must be integrated appropriately to fit in problem situations instead of being told in a book (Bransford, 1994; Jonassen, 1997). Therefore, ill-structured problems require structural knowledge, also referred a conceptual knowledge, in order to access meaningful information and principles rapidly when domain-specific knowledge is needed in problem solving.

Structural knowledge is the knowledge of how concepts with a domain are interrelated (Diekhoff, 1983) and engages the integration of declarative knowledge into useful knowledge structures (Jonassen, Beissner, & Yacci, 1993). Knowledge structure is an organized network of information stored in semantic or long-term memory (Champagne, et al., 1981a, p.87) and used to develop procedural knowledge for solving domain problems (Jonassen, Beissner, & Yacci, 1993).

Many researchers made assumption the ability to solve problems results from the complex interaction of the structure of knowledge in memory (Chi & Glaser, 1985; Glaser, et al., 1993; Robertson, 1990; Smith, 1992; Sugrue, 1995). In the study of Robertson's think-aloud protocols, he found that structural knowledge predicted strongly learners' transfer problem-solving ability in physics on a written exam (1995). Glaser's model (1993) described the importance of structured, integrated knowledge in problem solving as well. In the model, good problem solvers store coherent chunks of information in memory

and use organized information rather than isolated facts (Glaser, et al., 1993). In addition, Smith (1992) proposed structured knowledge as one of important cognitive components of problem solving. He argued that good problem solving requires knowledge of the domain which must be adequate, organized, accessible, and integrated (Smith, 1992). Simon (1973) insisted also that the solver should have the knowledge needed to utilize the appropriate components in the organization of the problem solution. Simon points out that solving ill-structured problems requires that the solver has appropriate conceptual knowledge of the components of the problem.

The importance of structural knowledge can be found in the processes of solving ill-structured problems. The representation is established by organizing appropriate elements in which a schema guides selection, instead of recognizing and classifying problem types (Voss & Post, 1988). In Johnson's study of house officer ratings, the data showed experts are likely to have clear-cut stop rules, such that a search is terminated as soon as enough information is obtained (Voss, et al., 1991). For example, as in constructing problem space, experts have a well-defined routine for searching out critical information and ability to terminate after immediately collecting a sufficient amount of cogent information (Voss, et al., 1991). Furthermore, experts have suitable conceptual knowledge of a problem domain, especially large amounts of problem-related information, stored in a long-term memory rather than constrained by the content domains being taught in lecture (Voss, et al., 1991).

In sum, domain-specific knowledge must be accessible when it is needed in problem solving. In order to do this, the domain-specific knowledge must be organized or assembled in a meaningful way, using some type of rule, with other concepts to result in a unique solution. Thus, for solving ill-structured problems, solvers must have structural knowledge that assembles a large amount of relevant, problem-related information from memory (Voss & Post, 1988).

Metacognition

Ill-structured problems have no clear solution and require the consideration of alternative goals as well as the handling of competing goals. Moreover, they require solvers to control and regulate the selection and execution of a solution process. That is, when goals or action alternatives are ill-defined, solvers have to organize and direct their cognitive endeavors in different ways and to a different degree. Individuals can not solve a problem in a straightforward manner. They have to use metacognitive skills such as change strategies, modify plans and reevaluate goals.

Knowledge of cognition.

Along with domain-specific knowledge and structural knowledge, ill-structured problem solving requires the use of appropriate general strategies in problem situations. Since ill-structured problems do not have obvious solutions and require large amount of information in various content areas, individuals rarely have enough knowledge to solve the problems. Therefore, domain-independent general strategies which can be applied to problems, regardless of content, are required to assist making progress on unfamiliar or nonstandard problems (Schoenfeld, 1983). Domain-independent general strategies may include argumentation strategies, decomposition, and metacognitive strategies.

In the social science study of Voss et al., (1991), they found experts were flexible in that they take into account more factors than do novices in searching for information. Additionally, non-Soviet experts used strategies of argumentation more often than novices. They concluded that argumentation may be an important strategy in solving ill-structured problem (Gick, 1986).

Decomposition can be one of domain-independent general strategies as well. Problem decomposition, or breaking the problem into subproblems, is a useful general searching strategy in solving problems such as the design in architectural problems (Simon, 1973) and the design of software (Jeffries, et al., 1981). In the interesting computer model expertise study, Larkin, et al found that decomposition strategy (e.g., recursive decomposition) were used successfully in solving problems in a variety of problem domains regardless of domain-specific knowledge (Larkin, et al., 1980). In addition, Clement (1984) found the expert scientists used decomposition, embedding the problem into a larger one, as solve unfamiliar physics problems. However, Polson & Jeffries (1985) argued that solvers must have knowledge of the techniques and domain for breaking the problem into subproblems. Therefore, the solvers who don't have schema in the domain, may have difficulty using the decomposition strategies (Polson & Jeffries, 1985). Further research requires to determine if the strategies used in the computer model are useful to other problem solving such as human problem solving (Gick, 1986).

Metacognitive strategies include planning, checking, and evaluation (Brown, et al., 1983). These strategies may be applied later in the solution process and involved in regulation of ill-structured problem solving. Researchers found that experts commonly used these strategies for checking the solution, or monitoring the progress, toward the goal as solving proceeds (Gick, 1986). In addition, Jonassen (1997) proposed the importance of metacognitive strategies in ill-structured problem solving. He argued that solvers have to

reflect on their own personal knowledge of a problem domain as faced unfamiliar problems. Gick (1986) described that experts have some fairly sophisticated information-gathering search strategies rather than solely general searching strategies to solve unfamiliar problems. However, there lacks of research studies about search strategies relating to unfamiliar problem solving. It is difficult to describe specific information-gathering search strategies in solving ill-structured problems.

General strategies are included in knowledge of cognition. Knowledge of cognition is one of major metacognitive components (Brown, 1987; Flavell, 1987; Jacobs & Paris, 1987). Knowledge of cognition includes three subprocesses such as “knowledge about self and about strategies, knowledge about how to use strategies, and knowledge about when and why to use strategies” (Schraw & Dennison, 1994). In solving ill-structured problems, solvers must have general strategies, as well as know how to use the general strategies. Although solvers possess these general strategies, they will employ them at inappropriate times unless they have conditional knowledge about when and why to apply. Thus, the solvers must have all three subprocesses of knowledge of cognition in order to employ general strategies effectively and appropriately in the solving ill-structured problems.

Regulation of cognition.

First, when information is obtained, either internally or externally, it is necessary for the solvers to evaluate the information with respect to its usefulness in solving a problem (Kluwe & Friedrichsen, 1985). The solver must have evaluating skills when determining the extent to which obtained information may be effectively used in the solution process, a solution process may anticipate the quality of the solution, and which selected goals may be important in a given situation (Kluwe & Friedrichsen, 1985). In Germany, Dorner and his research group show more successful problem solvers handling a complex problem by using evaluating activities as their own solution process (Dorner, et al., 1983). They are continuously analyzing and judging their solution process and evaluating possible solution directions, states, and consequences.

Second, monitoring is a primary component of ill-structured problem solving. When ill-structured problem situations are states of uncertainty, individuals fail easily to solve a problem because they lack the necessary knowledge needed to act in such a situation. In addition, individuals do not know how to find a solution path. In searching for the solutions to problems, this uncertainty requires monitoring of one’s own cognitive efforts, the effects of these efforts, the progress and the success of solution activity, keeping track of the solution activity and conflicts between different goals (Kluwe & Friedrichsen,

1985). Furthermore, the execution of plans must be monitored and regulated in order to insure that one's actions are directed toward the desired goal state.

In Sinnott's study, she argued that solvers frequently monitored their own processes, shifts, choices and styles. Successful problem solvers keep checking earlier states and initial data for enhancing and controlling their solution path of a problem, as well as ensuring they are on a promising track (Dorner, et al., 1983). In addition, the solvers also monitored their emotional reactions.

The monitoring process sometimes helped solvers stay on track and deal with their limitations, and also let them decide about the nature of the problem and the goal to choose. When solvers construct problem space, monitoring helps to link other problem spaces, regulates choice of problem essence, and maintains continuity. Successful problem solvers are significantly able to control their own cognitive process as well as apply appropriate general strategies. They monitor and check their cognitive states precisely, as well as regulate their own thinking.

Finally, planning is a primary everyday problem in the solving activity. Planning can be characterized as a dynamic transaction between lower and higher levels of decision making (Kluwe & Friedrichsen, 1985). Planning is also defined as conscious or deliberate predetermination of a sequence of actions aimed at accomplishing a problem goal (Rebok, 1989). Everyday problem solvers face a trade-off between the desire for a more complete and elaborate plan, and the need for flexibility of action. No strict separation is maintained between the planning and execution stages of problem solving. Novel plans emerge as previous goals are revised and replaced with new ones (Kluwe & Friedrichsen, 1985). These emergent constructions arise from immediate feedback on the success of completed actions, as well as from the problem solver's reflections on the outcome of those actions.

Good solvers must be able to establish suitable decision criteria, flexibly allocate their cognitive resources, review and evaluate previous decisions, carry out alternative plans as necessary, and formulate plans at high levels of abstraction (Voss, 1989). Individual differences in knowledge structures, component cognitive processes, motivational levels and problem-solving styles may explain some of the widespread variations in planning effectiveness (Rebok, 1989). In a study by Simon and Simon, they argued that the solution process of good problem solvers shows an increase readiness of planning, checking, and evaluation (1978).

Monitoring, evaluation, and planning are called regulation of cognition as a part of metacognition (Brown & Campione, 1981). In solving ill-structured problems,

metacognition is a critical component comprised of general strategies, monitoring, evaluating, and planning (Brown & DeLoache, 1978; Herbert & Diome, 1993; Kitchner, 1983; Kluwe & Friedrichen, 1985; Rebok, 1989; Simon, 1978).

Non-Cognitive Variables

Non-cognitive variables are important components with cognition and metacognition in solving ill-structured problems. Non-cognitive variables include affect, value, motivation, emotionality and attitude. Affect is referred to as an individual's positive or negative feeling about a particular idea, object, or event (Voss, 1989). Value is defined as a person's belief system.

In general, ill-structured problems possess multiple representations of the problem. Among competing problem spaces, the solvers must decide which of the schema is closely relevant and useful for solving by using their cognition or affective knowledge, including emotion, value, and belief (Sinnott, 1989).

Sinnott (1989) found that emotions and task-unrelated thoughts often were the impetus for choice of goal or problem essence. In her study, she proposed that the solvers seemed to exhibit an expression of some sort of "passionate commitment" to a choice of beliefs amid ultimate uncertainty (Polanyi, 1977). This commitment seemed to take the form of choice of problem space. Schoenfeld (1983) pointed out a number of ways that control level processes such as belief systems, influence intellectual performance. In addition, Voss (1988) found that an individual constructs personal life related goals, as well as a sense by which goals are to be accomplished.

In sum, non-cognitive variables encourage the choice of goal or problem essence, select information, keep the solver going, and motivate a solver to continue through the process (Jonassen, 1997). If the feelings constitute a strong effective reward by internal criteria, values and affects increase the solvers' persistence in the solution effort as well as keep awareness of the problem in the front of consciousness. The effect of such awareness is to be searching continuously for information that is potentially relevant to the problem. Continual awareness leads to an increase in one's knowledge, as well as to an increase in the use of search strategies (Voss, 1989). They kept the solver going, motivating solvers to continue through the process (Herbert & Dionne, 1993; Jacobson & Spiro, 1993; Jehng, Johnson & Anderson, 1993; Schommer, 1993; Tyler & Voss, 1982).

Justification Skills

Since ill-structured problems have commonly divergent or alternative solutions, solvers must support their decision by providing evidences or claims. When the solvers delineate the causes of the problem in a problem statement, they must develop justification or an argument for supporting the rationale of their selection of a particular cause (Voss, 1988; Voss & Post, 1989). In addition, when selecting a solution, the solvers have to construct how they came to that decision by providing the most viable, defensible and cogent argument (Jonassen, 1997). The developing arguments support the solvers' decision and defend it against alternatives.

The process of justification requires the solvers identifying as many as possible of the various perspectives, views and opinions which may occur in the problem situation, supporting arguments and evidences on opposing perspectives, evaluating information, and developing and arguing for a reasonable solution (Voss, 1989, 1991). Reconciling different interpretation of phenomena based on solvers' goals or perception of the nature of the problem is a critical process in developing justification (Churchman, 1971).

Thus, the solver's epistemic cognition is an important component in order to develop justification besides cognition and metacognition (Kitchener, 1983). Kitchener described that epistemic cognition is knowing about knowledge (1983). When individuals are engaged in selecting a solution among different alternative solutions in complex everyday problems, they invoke to epistemic processes such as the truth value of alternative solutions (Kitchener, 1983). For example, if individuals believe all problems exist an objective, absolute solution, they may try to apply the correct procedure to insure a valid and true solution rather than consider several potentially valid perspectives on ill-structured problems (Kitchener, 1983).

In sum, successful ill-structured problem solvers must develop and justify their position to provide warrants for their own interpretations and judgments. For developing justification, individuals need epistemic cognition in order to understand that problems do not always have a correct solution but better or worse one; why alternative solutions can be afford and how to choose between them. Depending epistemic assumptions, individuals understand the nature of such problem, and define and choose acceptable strategies or solution in ill-structured problems (Kitchener, 1983). However, in this study, epistemic cognition is not included in problem-solving components although it is an important component. There are not many current research relating to epistemic cognition. Moreover, most of the epistemological research have focused on learning for young students and

knowledge for adults (Schommer, 1990, 1993). Because of lacking available instruments for measuring epistemic cognition of young students, students' justification skills will be tried to measure directly based on students' written responses.

Summary of Components for Solving Ill-Structured Problems

Well-organized knowledge structure is required to construct a problem space. Well developed domain-specific knowledge and structural knowledge may enhance problem-solving ability in any particular domain in ill-structured problem solving. In addition to domain-specific knowledge and structural knowledge, ill-structured problem solving requires epistemic cognition for developing an argument, metacognition (e.g., general strategies, monitoring, evaluation, planning), and non-cognitive variables (e.g., value, affect, emotionality). All these components are equally important to solve ill-structured problems.

Differences Between Well-Structured and Ill-Structured Problems

Many researchers argued that ill-structured problem solving is more complicated than well-structured problem solving (Herbert & Dionne 1993; Korpi, et al., 1991; Sinnott 1989; Voss, et al., 1991; Voss 1988; Voss & Post 1989). Furthermore, the Reflective Judgment model and associated Interview (RJI) ascertained that well-structured problem-solving skills are not sufficient for solving ill-structured problems (Brabeck & Wood, 1990; Kitchener & King, 1981; Mines, et al., 1990; Wood, 1990; Wood & Games, 1991).

There are critical differences between the two problems as shown by the literature review. Well-structured problems require cognition, including domain-specific knowledge and structural knowledge, and knowledge of cognition (e.g., general strategies). However, ill-structured problem solving requires regulation of cognition, epistemic cognition, and non-cognitive variables, besides cognition and knowledge of cognition.

In the metacognition components, knowledge of cognition (e.g., general strategies) is sufficient for well-structured problems but not ill-structured problems. Ill-structured problem solving requires knowledge of cognition, as well as regulation of cognition including planning, monitoring, and evaluation because of complexity of problems.

Epistemic cognition and non-cognitive variables are critical components for ill-structured problem solving but not for well-structured problem solving. In well-structured problems, there is only one correct, guaranteed solution, achieved by using specific preestablished rules and procedures. Well-structured problems require finding and

applying the correct algorithm for successful solution rather than decision-making using epistemic cognition and their value or perception about problems (Churchman, 1971). Therefore, solvers do not need to consider alternative arguments, finding new evidences or evaluating the collected information for successful solution of well-structured problems (Kitchener, 1983).

In the contrast to well-structured problems, ill-structured problems have multiple potential valid solutions which can be effectively determined by using a particular decision-making procedure. Solvers must use their epistemic cognition, value, attitude, belief, motivation and emotion in order to make decisions in novel real life problem situations. Additionally, they have to develop arguments by gathering evidences, expert opinions, and reasons, and by integrating or synthesizing diverse opinions and information for supporting their decision (Kitchener, 1983). In sum, well-structured and ill-structured problems are different, based on the nature of the problem, solving processes, and solving components as shown in Table 2.2.

Table 2. 2

Summary of Differences between Well-Structured and Ill-Structured Problems

Criteria	Well-Structured Problems	Ill-Structured Problems
<u>Nature of Problems</u>		
Components of Problem Statement	<ul style="list-style-type: none"> • A known goal state. • A well-defined initial state, constrained set of logical state. • Constraint parameters. 	<ul style="list-style-type: none"> • Vaguely defined number of goals. • Incomplete and inaccurate or ambiguous uncertain information. • Inconsistent relationship between concepts, rules, and principles among cases based on context.
Solution	<ul style="list-style-type: none"> • A single correct, convergent answer to reach a satisfaction in a final solution. 	<ul style="list-style-type: none"> • Multiple solutions, solution paths, or no solution at all. • No one universal agreement on the appropriate solution.
<u>Processes of Solving Problems</u>		
Representation Problems	<ul style="list-style-type: none"> • Activating Schema 	<ul style="list-style-type: none"> • Searching information. • Selecting information. • Developing justification about the selections.
Solution Processes	<ul style="list-style-type: none"> • Searching solution 	<ul style="list-style-type: none"> • Generating solutions. • Selecting a solution.
Monitor	<ul style="list-style-type: none"> • Implementing solution 	<ul style="list-style-type: none"> • Evaluating the solution, monitoring solving processes, and developing justification.
<u>Components for Solving Problems</u>		
Cognition	<ul style="list-style-type: none"> • Domain-specific knowledge • Structural knowledge 	<ul style="list-style-type: none"> • Domain-specific knowledge • Structural knowledge
Metacognition	<ul style="list-style-type: none"> • Knowledge of cognition 	<ul style="list-style-type: none"> • Knowledge of cognition • Regulation of cognition
Non-cognitive variables		<ul style="list-style-type: none"> • Value/Attitude/Beliefs
Justification skills		<ul style="list-style-type: none"> • Ability to develop argumentation

Research Hypotheses

This investigation will examine the theory that ill-structured problem solving requires more qualitative components than those of well-structured problems. As described in the literature review, cognition and knowledge of cognition are sufficient components for solving well-structured problems. Ill-structured problem solving, however, requires justification skills with epistemic cognition, regulation of cognition and non-cognitive variables (e.g., attitude, value, beliefs, motivation) in addition to cognition and knowledge of cognition

To evaluate the importance of cognition and knowledge of cognition in well-structured problem solving, the amount of variance in student well-structured problem-solving scores attributable to cognition and knowledge of cognition components will be tested.

To evaluate the importance of cognition, metacognition, justification skills, and non-cognitive variables in ill-structured problem solving, the amount of variance in student ill-structured problem-solving scores attributable to these components will be tested.

This evaluation will identify the variable components which are most important in explaining well-structured and ill-structured problem-solving skills. The following research hypotheses will be tested:

Hypothesis 1. Scores of domain-specific knowledge, as measured by Cognition Inventory (CI), will be a significant predictor of scores on well-structured problem-solving tasks measured by Well-Structured Problem-Solving Processes Inventory (WPSPI).

Hypothesis 2. Scores of structural knowledge, as measured by CI, will be a significant predictor of scores on well-structured problem-solving tasks measured by WPSPI.

Hypothesis 3. Scores of knowledge of cognition, as measured by How Do You Solve Problems inventory (HSP), will be a significant predictor of scores on well-structured problem-solving tasks measured by WPSPI.

Hypothesis 4. Scores of domain-specific knowledge, as measured by CI, will be a significant predictor of scores on ill-structured problem-solving tasks measured by Ill-Structured Problem-Solving Processes Inventory (IPSPI).

Hypothesis 5. Scores of structural knowledge, as measured by CI, will be a significant predictor of scores on ill-structured problem-solving tasks measured by IPSPI.

Hypothesis 6. Scores of knowledge of cognition, as measured by HSP, will be a significant predictor of scores on ill-structured problem-solving tasks measured by IPSPI.

Hypothesis 7. Scores of regulation of cognition, as measured by HSP, will be a significant predictor of scores on ill-structured problem-solving tasks measured by IPSPI.

Hypothesis 8. Scores of justifications skills, as measured by Justification Inventory (JI), will be a significant predictor of scores on ill-structured problem-solving tasks measured by IPSPI.

Hypothesis 9. Scores of attitude, as measured by Test of Science-Related Attitude (TOSRA), will be a significant predictor of scores on ill-structured problem-solving tasks measured by IPSPI.

Hypothesis 10. Scores of motivation, as measured by Test of Motivation in Astronomy (TMA), will be a significant predictor of scores on ill-structured problem-solving tasks measured by IPSPI.

Chapter Summary

It is critical that the skills needed to solve everyday problems be included in K-12 education. This investigation is being conducted to extend the findings of past research studies relating to ill-structured problem solving, and to verify their results using a larger sample in the science classes.

This chapter has reviewed two major topics, well-structured and ill-structured problems. The characteristics of each were described, including the nature of the problem, the solving processes, and the solving components. Secondly, well-structured and ill-structured problems were compared in order to present critical differences.

In the following chapter, the method of the investigation used to verify the results of past studies is described. If it is found that the solving processes differ between ill-structured and well-structured problems, educators need to apply different approaches to facilitate students' everyday ill-structured problem solving at the high school students' level.

CHAPTER 3. METHOD

Participants

The target population of this study was 9th-grade students enrolled in science classes using the integrated multimedia program *Astronomy Village (AV)*. The accessible population was 9th-grade science students in schools registered to use *AV*. Subjects were drawn from a random sample of 9th-grade science students in schools using *AV* who volunteered to participate in this research study.

To obtain a sample, teachers from across the country who planned to use *AV* in their classrooms Fall, 1997, were mailed a recruitment letter or contacted by phone to encourage their participation in this study. See Appendix A. Once their help was enlisted, they were sent a set of instructions and the research materials.

The participants in this study were 124 9th-grade students attending a high school in a small working-class community near a large city in the Midwest. All 9th-grade students enrolled in the earth and space science course were invited to participate. Both parents and teachers were asked to complete a consent form before any data was collected. A letter informing parents of the purpose of the study and requesting permission for their child to participate was sent to each student's home.

From a total of 124 students, six students were absent on the days the surveys were administered, as well as on a makeup day one week later. The 118 students were used in the well-structured problem-solving analysis. However, six students were deleted from the ill-structured problem-solving analysis. Since the six students conducted research on site selection, which was one of ill-structured problems in the study, they already knew the content area of the site selection so that it was not an ill-structured problem to them. In order to obtain appropriate data, only the remaining 112 students were used in ill-structured problem-solving analysis as final samples. Of the 118 students who completed surveys, 111 (94 %) students, including 56 females and 55 males, were Caucasian (White). Two female students (2%) were African American. One male student (1%) was Asian American. Four students (4%), including three females and one male, were Hispanic. The gender breakdowns of the final samples were 61 females (52%) and 57 males (48%).

Research Design

This study was a non-experimental, correlational analysis of the predictors of well-structured and ill-structured problem-solving skills. Seven predictor variables included domain-specific knowledge, structural knowledge, justification skills, attitude, motivation, knowledge of cognition, and regulation of cognition. Knowledge of cognition is a general strategy and one aspect of metacognition. Regulation of cognition including evaluation, monitoring, and planning is one of the components of metacognition as well.

An analysis investigating the relationship between students' well-structured problem-solving scores and the predictor variables of a) domain-specific knowledge, b) structural knowledge, c) justification skills, d) attitude, e) motivation, f) knowledge of cognition, and g) regulation of cognition was conducted. For ill-structured problem solving, the same analysis employed in the examination of well-structured problems was conducted. Table 3.1 is an overview of the two criterion variables and the seven predictor variables for this study.

CV1 denotes the well-structured problem-solving scores (WPS). The well-structured problem-solving scores were defined as the score obtained from well-structured problem questions. CV2 indicates the ill-structured problem-solving scores (IPS). The scores were obtained from ill-structured problem questions.

Materials

In this study, the instructional context was Nearby Star research investigation in *Astronomy Village*. There were seven predictor variables including domain-specific knowledge, structural knowledge, justification skills, attitude, motivation, knowledge of cognition, and regulations of cognition, as well as two criterion variables including well-structured problem-solving skills and ill-structured problem-solving skills. Various instruments were employed to collect the appropriate data to measure each variable.

Table 3. 1

Summary of Variables

Identifier	Description	Short Name
Criterion Variables		
CV1	Well-structured problem-solving scores	WPS
CV2	Ill-structured problem-solving scores	IPS
Predictor Variables		
Cognition		
	Domain-specific knowledge	DK
	Structural knowledge	SK
Justification Skills		
	Ability to develop justification Skills	JUSTIFY
Non-Cognitive Variables		
	Attitude	ATTI
	Motivation	MOTIVE
Metacognition		
	Knowledge of Cognition	KCOG
	Regulation of Cognition	RCOG

Instructional Context

In this study, *Astronomy Village (AV)*, a multimedia software program, was used as the instructional environment. Ten investigations cover a broad cross-section of current research area in astronomy. Students of the study selected Nearby Star, one of ten research investigations, to understand the processes of scientific inquiry as well as astronomical and mathematical concepts. The students participated in scientific inquiry members of a cooperative learning group. Their project was to determine the distance of the Nearby Star from the Earth.

In the first phase called Background Research, students collected relative information by reading articles at AV Library, and listening to lectures at the AV Conferences. The background research included parallax principles, Earth motion,

characteristics of Nearby Stars, principles of trigonometric, and the measurement of distance of Nearby Stars.

After collecting appropriate information, the students observed stars and took images at the AV observatory to identify Nearby Stars in our galaxy. Based on the recorded images, they observed the movement of stars in the sky and calculated the positional shift during the six month period at Image Processing Lab. This process is called the Data Collection phase.

The students analyzed the collected data to calculate the parallax angle of the Nearby Star and used it to calculate the distance of the Nearby Star from the Earth. Based on the results, the students interpreted how star movements in the sky can be employed to measure the distance of Nearby Stars. These phases were called Data Analysis and Data Interpretation. Finally, each student team presented its procedures and results to the class.

Metacognition Measures

How Do You Solve Problems (HSP) was used to measure metacognition, including knowledge of cognition and regulation of cognition. See Appendix B. HSP was adapted from Fortunato, Hecht, Tittle, and Alvarex (1991). The 21 metacognitive statements were based on the writing of Schoenfeld (1985) and Corno et al., (1983). The original version of the instrument was developed on a three-point (no, maybe, and yes) Likert type scale with four different subscales, including planning, monitoring, evaluating, and specific strategies of a mathematics word problem. Items were revised by Ennison, et al., (1995), and the final version of the instrument consists of 21 Likert type statements with a five-point scale (strongly disagree, disagree, neutral, agree, strongly agree).

Using the classical item analysis method, three items were deleted from the original 21 items. The 118 students were not a large enough sample size to conduct factor loading, however, the tentative results indicated that the 18 items on this instrument cluster into four factors, explaining 89 % of the item covariation, using the Principal Axis Factoring method and Promax rotation method. Although the HSP was intended to measure four different aspects of metacognitive skills, a factor correlation matrix showed overall high relationship among four factors ranged from .47 to .62. Thus, the Promax was appropriate to be used as a rotation method in factor analysis of HSP inventory.

Indicators which had loading above .3 were listed for each factors. The four factors are reflection, planning and monitoring, problem-solving strategies, and information-

selection strategies (see Appendix C). The internal consistencies of the four subscales ranged from .70 to .87 (mean = .78). In the analysis, the planning and monitoring factor used the regulation of cognition variable. The combined score of the problem-solving strategies and the information-selection strategies was used as the knowledge of cognition variable.

Parallel analysis (Horn, 1965) was used to verify the factor analysis of the HSP inventory (see Table 3.2). Parallel analysis is a comparison of eigenvalues, comparing a sample-based adaptation of the K1 method (Horn, 1965) and the population-based K1 method (Kaiser, 1960).

Table 3. 2

Comparison Eigenvalues between K1 Analysis and Parallel Analysis in HSP (n = 118)

Factor	<u>K1 Analysis</u>			<u>Horn's Parallel Analysis</u>		
	Eigenvalue	% of Var. Explained	Cum. % Variance	Eigenvalue	% of Var. Explained	Cum. % Variance
1	6.601	36.675	36.675	1.568	15.681	15.681
2	1.540	8.555	45.230	1.355	13.546	29.227
3	1.326	7.368	52.597	1.144	11.439	40.666
4	1.140	6.331	58.929	1.018	10.182	50.848

Horn (1965) suggested components of greater eigenvalues obtained from the population-based K1 method would be retained as factors rather than those of the comparison random matrix based on the same sample size. Four factors in components of the matrix have greater eigenvalues than those of the comparison random matrix. The Parallel analysis showed HSP has four factors, which is consistent with the results of K1 analysis.

Non-Cognitive Variables Measures

Test of Science-Related Attitude

Values, attitude, and belief toward science was measured using the Test of Science-Related Attitudes (TOSRA). This instrument, developed in Australia by Fraser (1978), underwent a validation study (Smist, Archambault, & Owen, 1994) to estimate its reliability and validity with American high school students. See Appendix B. The 70 items on this instrument cluster into six factors, explaining 81% of the item covariation. The six factors are attitude toward science career & leisure enjoyment, preference for experimentation, social importance of science, normality of scientists, attitude toward science classes, and openness to new ideas. The internal consistencies of the six subscales ranged from .72 to .94 (mean = .85).

Test of Motivation in Astronomy (TMA)

The investigator developed nine items to measure motivation toward astronomy (Fraser 1978). See Appendix B. The questionnaire originally included ten items. One bad item was deleted based on the result of the classical item analysis. The nine items on this instrument cluster into one factor, explaining 91% of the item covariation. The factor detected was general motivation toward astronomy.

Scree test (Cattell, 1966) and Parallel analysis (Horn, 1965) were used in order to verify the factor analysis. In the Scree test of the eigenvalues plot, it found a sharp slope from lower to higher eigenvalues and one break point in the line. There was only one factor above the falling line (see Figure 3.1). Cattell (1966) described the rule that those falling above the line would be retained as a factor.

Moreover, one eigenvalue was greater than those of the comparisons random matrix in Parallel analysis (see Table 3.3). The results showed that the nine items of testing motivation in astronomy measured one construct: general motivation toward astronomy.

Figure 3.1. Scree Test of the TMA Eigenvalues Plot

Table 3. 3

Comparison Eigenvalues between K1 Analysis and Parallel Analysis in TMA (n = 118)

Factor	<u>K1 Analysis</u>			<u>Horn's Parallel Analysis</u>		
	Eigenvalue	% of Var. Explained	Cum. % Variance	Eigenvalue	% of Var. Explained	Cum. % Variance
1	5.240	58.224	58.224	1.568	15.681	15.681
2				1.355	13.546	29.227
3				1.144	11.439	40.666
4				1.018	10.182	50.848

Problem-Solving Processes and Component Measures

Several instruments measured the students' holistic problem-solving processes and components using multiple choice and written essay questions. The instruments had mainly been developed with consideration for construct validity.

In order to select appropriate problems and insure the validity of the measurement process, two subject matter experts were interviewed to learn how a good problem solver represents solving processes in an astronomy context. Additionally, solving processes of well-structured and ill-structured problems in astronomy were analyzed (Bransford 1994; Jonassen 1997; Sinnott 1989; Voss & Post 1988; Wood 1994). Based on subject matter experts' comments, on a literature review, and on National Science Education Standards (1996), test items were developed to measure a learner's problem-solving skills in various problem situations.

A team of three people, made up of one astronomer and two researchers, drew up two ill-structured problems and six well-structured problems. Problem topics included Nearby Stars, Searching for a Supernova, and Variable Stars from *AV*. As the testing items were developed, other tests that measure similar constructs, including CoViS's (1996) and CRESST's (1994) test items, were used as references.

These eight problems were examined by two astronomers, one senior researcher in astronomy and two experts in test development. They evaluated the questions to determine whether the questions measure learner's scientific processes in astronomy and represent content covered by *AV*. Three science teachers also reviewed the eight problems to evaluate the readability, the vocabulary level, and the appropriate construction for 9th-grade students. Using this process, language-appropriate test items were developed for the target population of 9th-grade science students in USA public schools.

After revising the test items based on a critical review of the prototype by experts and teachers, the prototype was tried out with three 9th-grade students. They did not participate in the main study and had experience working on the *AV* program. Their think-aloud protocol was recorded to assess their confusion and difficulty during problem solving. The procedure for the trial test was to have each student individually read the problem aloud to the researcher. Words that the students did not know were recorded. The student was then asked to define several words from the paragraph. Finally, the students were asked to solve the problems. After finishing the test, brief discussion was conducted to verify what each thought the problems were about.

After revising the test items based on the trial, the revised version of the problems was sent to two astronomers and two experts in test development. They evaluated the revised problems to make sure they were developed appropriately with regard to content.

On the basis of the experts' feedback and the trial tests, the revised prototype was given a second trial testing with two 9th-grade science students who did not participate in the main study and had experiences with the *AV* program. The procedure was the same as the first trial testing. The prototype was revised from the second trial and a final version developed.

Well-Structured Problem-Solving Processes Inventory (WPSPI)

Problem solving exercises were developed to measure learners' well-structured problem-solving processes in science (CoVis, 1996). Well-Structured Problem-Solving Processes Inventory (WPSPI) included two well-structured problems which measure students' well-structured problem-solving skills based on the content covered in *AV* during the three weeks of instruction. Students were required to present and explain their approach for solving well-structured problems (see Table 3.4).

In the well-structured problem-solving analysis, two well-structured problem scores were combined into overall well-structured problem-solving scores. Since two problems were intended to measure problem-solving skills within the Nearby Star problem contexts, the both problems required similar domain-specific knowledge and structural knowledge to find a solution. Additionally, some of solution processes were redundant in the two problems. Because of the similarities between two problems, most students answered the questions in one solution instead of two separate solution processes. The combined scores were used as well-structured problem-solving scores in the analysis.

Table 3. 4

Example of Well-Structured Problem Testing Items

You are a member of a research team that has been asked to calculate the distance to a star. A famous astronomer has suggested that the star is relatively close to Earth (within 25 light years). You have been asked to meet with the press to discuss; A) how the team will proceed with this research and B) what calculations you will conduct.

- Assume that the people who will be reading your explanation have little or no knowledge of astronomy.
- Write your explanation so that it is clear enough for anyone to understand.
- Make sure you provide specific details of the procedures you will follow to measure the distance.
- You may want to use drawings to illustrate your thinking.

Problem 1. How will you **measure the distance** to the star?

Problem 2. What calculations will you conduct? Be sure to describe how these calculations will help you **measure the distance** to the star.

Ill-Structured Problem-Solving Processes Inventory (IPSPI)

Ill-Structured Problem-Solving Processes Inventory (IPSPI) was developed to measure ill-structured problem-solving skills. It assessed students' ill-structured problem-solving skills in two novel problems or situations. Students were required to plan their approach by defining problems and goals, searching and selecting appropriate information, organizing selected information, choosing a potential solution, and developing justification of their solution and selections. Furthermore, the tasks do not have single correct solutions. Instead, students must depend on their reasoning to find a potential solution based on their acquired skills for solving problems.

Two ill-structured problems required different domain-specific knowledge and structural knowledge. Moreover, problem situations are different between the two problems. One of the two problems is similar in content to the Nearby Star unit which these students studied for three weeks (see Table 3.5). It is called a "near-transfer" ill-structured problem because this problem required the content understanding of Nearby Star to find a solution.

Table 3.5

Example of Near-Transfer Ill-Structured Problem Testing Items

Dr. Smith, an astronomer, recently announced that a major emergency will be occurring soon. He believes that there is a good chance that a very large asteroid will hit Earth soon.

You have been hired by an international agency to organize and direct the efforts of a research team that will investigate Dr. Smith's claims and report your conclusions. If you believe that Dr. Smith's claim might be true, you should investigate the matter further. Among the factors that you must consider are where the asteroid might hit, how large the force of the explosion will be, what effects the impact might have on the global and local population, and possible ways to defend against impact.

Based on your advice, the agency will decide whether to fund either an early warning plan or some type of defensive technology, and how much money to allocate from a very limited budget. As director of this effort, you will have sole responsibility for preparing for this potential crisis. What types of experts will be needed to assist you in your research? Write an explanation of your choice of team members that is clear enough for others to understand. Specify all aspects of the situation that helped you to reach your conclusions.

The other problem did not require content understanding but had different problem context than that of Nearby Star (see Table 3.6). It required, however, scientific principles and processes which students acquired during the three weeks of the Nearby Star research investigation. The problem was called a "far-transfer" ill-structured problem. In the analysis of ill-structured problem solving, the two problems were analyzed separately to determine whether results were consistent between the two different ill-structured problems.

Table 3. 6

Example of Far-Transfer III-Structured Problem Testing Items

You are a member of a research team that is looking for a site on which to build a new telescope. These conditions are important, not just now, but for the next 100 years that this telescope may be in use and for future telescopes that may be built here. In reality, it is unlikely that you will find a site that satisfies all of the requirements. However, there are three possible sites. Your team has been given the opportunity to interview representatives from each of the potential sites. Based on the interviews, your research team has gathered the following information:

Blanco Peak - For more than twenty years on Blanco Peak, Yunque University has operated a small observatory on that specializes in stellar photometry. It has passable roads year-round, electricity, water, and nearby lodging. The observatory is located at an elevation of about 9,300 feet in the Quetzal National Forest, about 40 miles southeast of Alberro. Alberro, with a population of 1,200,000 has been cited as one of the fastest growing cities in the country. The weather is clear 300 out of 365 days a year.

South Verde - A 10,783-foot peak, located 17 air miles southwest of Saberro, may be accessed by an unpaved road, which is occasionally impassable in bad weather. Saberro is a medium-sized city of about 350,000. The cost of living is high. Although power lines reach the observatory, the staff would have to truck water up to the site. Located on the ridge are the Irving Langmuir Laboratory for Atmospheric Research, the NASA Observatory for Comet Research, and an automated supernova-search telescope constructed by astronomer Stirling Colgate. The area typically has dark skies, which are clear 350 out of 365 days a year.

Clamente Peak - The National Solar Observatory (NSO), located in Bayspot, is about 70 miles northeast of Las Uesas. Uesas is a small city of 50,000, which has little development potential. On a ridge three-quarters of a mile south of the NSO is Apache Point (9,215 feet), site of an observatory being constructed by a consortium led by the University of Washington, Seattle and the University of Chicago. This well-developed peak can be reached by an excellent road and has electricity and water. There are currently no bedding facilities located nearby. The skies are clear 250 out of 365 days a year.

Based on the information, you have to decide which site will provide the right balance between observation needs and budgetary limitations. People at the funding agency that will grant the money know little or nothing about astronomy. Provide an explanation of your decision that is clear enough for the funding agency to understand.

Cognition Inventory (CI)

The investigator and a research team at the NASA Classroom of the Future (COTF) developed the Cognition Inventory (CI) to measure domain-specific knowledge and structural knowledge (COTF, 1997). Students were asked to classify important concepts relating to a research study by checking among various concepts to measure their domain-specific knowledge (CoVis, 1996; Clark, 1990) as following in Table 3.7.

Additionally, they were asked to describe the relationships between the chosen concepts for answering structural knowledge questions (Jonassen, Beisser, & Yacci, 1993). See Table 3.7. For ill-structured problem solving, students' structural knowledge was measured in the processes of solving ill-structured problems. Since the nature of ill-structured problem solving requires solvers to organize the selected information in a problem situation for a successful solution, students must utilize structural knowledge by integrating appropriate information in their solution processes.

Justification Inventory (JI)

The Justification Inventory (JI) was developed to measure students' ability to develop arguments. As noted in the literature review, students' justification skills were measured based on their written responses.

In well-structured problems, the investigator defined justification skills by providing logical argumentation of the importance of given questions. Justification skills in well-structured problems were measured by three questions that ask students to justify their answers to questions in the research study (see Table 3.8).

Table 3. 7

Example of Domain-Specific Knowledge and Structural Knowledge Testing Items

1. Domain-Specific Knowledge

You are a member of a research team that has been asked to locate a star in a nearby galaxy. This star could be used to help find the distance to that galaxy. Put an “X” in the boxes next to the **five** concepts (ideas) that are **most important** for measuring the distance to the star in the nearby galaxy.

Trajectory.....	<input type="checkbox"/>	Transparency.....	<input type="checkbox"/>
Change in brightness.....	<input type="checkbox"/>	Measure of parallax.....	<input type="checkbox"/>
Earth’s motion.....	<input type="checkbox"/>	Pulsating star.....	<input type="checkbox"/>
Angle.....	<input type="checkbox"/>	Variable star.....	<input type="checkbox"/>
Triangulation.....	<input type="checkbox"/>	Nearby star.....	<input type="checkbox"/>
Atmosphere.....	<input type="checkbox"/>	Velocity.....	<input type="checkbox"/>
Meteorite.....	<input type="checkbox"/>	Gravitational collapse.....	<input type="checkbox"/>
Temperature.....	<input type="checkbox"/>	Inverse square law.....	<input type="checkbox"/>
Mass of star.....	<input type="checkbox"/>	Classification of star type.....	<input type="checkbox"/>
Light pollution.....	<input type="checkbox"/>	Size of star.....	<input type="checkbox"/>
Probability.....	<input type="checkbox"/>	Diffraction.....	<input type="checkbox"/>

2. Structural Knowledge of Well-Structured Problem

How are the concepts you checked related to one another?

- If you think there are any additional concepts that would help you explain your research, be sure to include them.
- Remember to describe how these additional concepts are related to the ones you checked.
- You may want to use drawings to illustrate your thinking.

3. Structural Knowledge of Ill-Structured Problem

Look back over your explanation and write down all the important ideas (or concepts). Describe how the above ideas (or concepts) are related to one another in your decision. You may want to use drawings to illustrate your thinking.

Table 3. 8

Testing Items for Measuring Justification Skills in Well-Structured Problems

Dr. Pamela Yang recently announced that she and her team have successfully measured the distance to a previously undiscovered star, thought to be located relatively close to the Earth. You have been asked to interview her team of astronomers and to ask the following questions:

- A) What were the observational periods?
- B) What particular mathematical equations did you use in your research?
- C) Did the distance to the star from Earth affect your choice of mathematical equation?

Explain **why these questions are important**.

Justification skills for ill-structured problems was defined as the ability to support the rationale of their selections. Since the nature of ill-structured problem solving requires solvers to develop arguments for a successful solution, students must also develop justification of their solution and decision. Thus, students' justification skills were measured in the processes of solving problems.

In the case of the near-transfer ill-structured problem, students' justification skills were measured by how they described the logical procedures they used to select team members. Their ability to defend their decisions against alternatives was also assessed. The testing item of justification skills and criteria of scoring system in the near-transfer ill-structured problem is described in Table 3.9.

Finally, in the far-transfer ill-structured problem, justification skills was measured by how well students were able to provide logical alternative suggestions to overcome the drawbacks of their selection and explain why other sites were less advantageous. Thus, justification skills in the far-transfer ill-structured problem was focused on measuring how the students provided their rationale for choosing the site in spite of the limitation by comparing other alternative sites (see Table 3.10).

Table 3. 9

Testing Item for Measuring Justification Skills in Near-Transfer III-Structured Problem

<p><u>1. Testing Item</u></p> <p>Based on your advice, the agency will decide whether to fund either an early warning plan or some type of defensive technology, and how much money to allocate from a very limited budget. Write an explanation of your choice of team members that is clear enough for others to understand.</p> <p><u>2. Criteria of Scoring System</u></p> <ul style="list-style-type: none"> - shows logical procedures for selecting members, including at least three of the following elements: <ol style="list-style-type: none"> 1) Confirm the prediction, 2) If yes, where, how large, 3) What impact on global population, 4) Possible defense methods and ways to protect population. - gives complete and clear responses of the selecting procedures with logically sound and systematic explanations. - explanations focus on scientific perspectives.
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Table 3.10

Testing Item for Measuring Justification Skills in Far-Transfer III-Structured Problem

<p><u>1. Testing Item</u></p> <p>People at the funding agency that will grant the money know little or nothing about astronomy. Provide an explanation of your decision that is clear enough for the funding agency to understand.</p> <p><u>2. Criteria of Scoring System</u></p> <ul style="list-style-type: none"> - presents the scientific drawback in a chosen site. - provides logical alternative suggestions to overcome the drawback in a chosen site, or main reasons for choosing this site in spite of the limitation. - gives clear explanations. - proposes scientific drawbacks of both two unchosen sites. - gives logical and scientific explanations of the drawbacks.
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Developing Scoring System

A generalized judgmental rubric system, based on performance criteria, was used to score students' responses (Blum, & Arter, 1996). The investigator developed the general rubric system, based on research studies (Baxter, Glaser, & Raghavan, 1993; Lane, 1993) which can be applied across domains. See Appendix E. Each trait was assigned a value on a scale from zero to four, using adjectives and descriptive phrases.

To develop a specific scoring system, samples of thirty students' responses were selected randomly to be used as a pilot. Based on the general, predetermined rubric system, the investigator placed the students' responses into five categories, scaled zero to four. As the students' responses were sorted, the investigator recorded reasons, including all evaluative comments to justify the category decisions if they were not included the predetermined rubric systems. The investigator kept reading student work and placing it into categories until they were not adding anything new to the list of attributes in criteria.

Based on the evaluative comments, similar attributes were clustered together to revise traits or dimensions of the general, predetermined rubric system. Finally, samples of student work were chosen to illustrate good examples of each scale point. The descriptions of each trait were tested, and modified in order to reach consensus on the categories that best describe the student's responses. The revised specific rubric system was reviewed by two content experts, a senior researcher, and a research associate of COTF. They evaluated the scoring system to make sure it was developed appropriately and include all important aspects for measuring students' problem-solving skills in astronomy.

Construct Validity of Scoring System

Before using the final version of rubric system, it was tested for construct validity using a comparison between novices' and experts' responses. To support the construct validity of the well-structured problem scoring system, the method of testing instructional sensitivity was chosen. Ten students who took the earth and space science course and conducted AV research were selected as an expert group. Ten students who did not take the earth and space science course nor conduct AV research were selected as a novice group. They were asked to complete well-structured problem-solving tests including items of domain-specific knowledge, structural knowledge, and justification skills.

Ten raters were selected to score the students' responses using the scoring systems. The raters consisted of teachers with experience in developing rubrics, senior researchers in

educational psychology, graduate students majoring in assessments or problem-solving processes, and a physics professor. The raters were divided into two groups. One group of five raters was assigned to score well-structured problem-solving tests. The other group was assigned to score ill-structured problem-solving tests.

All student responses were typed in order to eliminate differences in hand writing between experts and novices. The typed responses were shuffled to randomly mix the order of experts' and novices' responses. Thus, the raters did not know which were experts' and novices' answers when they scored.

Before scoring the twenty responses, the final version of the scoring system and the three sample responses were sent to ten raters. The raters were asked to score three students' responses using the scoring system, comment on the difficulty they experienced in scoring and offer general opinions of the rubrics. They scored the three samples and recorded their comments on the scoring system, such as which points they judged to be difficult or confusing. Based on their comments, the scoring system was revised in order to clarify the ambiguous scoring system.

The finalized scoring system was sent to the raters through the mail, including scoring sheets and twenty responses. No training in scoring procedures was included. After scoring, the raters sent their scores to the investigator through e-mail or fax. Then raters' scores were added together and a simple t-test was conducted to determine a statistical difference between the expert and novice groups. The mean difference between two groups was 4.04 ($p < .000$) of well-structured problem-solving skills, and 1.58 ($p < .001$) of well-structured justification skills. The expert group obtained significantly higher scores than those of the novice group.

To further support construct validity of ill-structured problem scoring system, one of the two ill-structured problem scoring systems was selected. Since two ill-structured problem scoring systems were developed based on one conceptual framework, one of the two ill-structured problem scoring systems could be used as a representative ill-structured problem scoring system. Additionally, the representative scoring system was judged by the ten raters to be less clear and contain less organized rubrics than those of the other.

Astronomy teachers, astronomers, and professors of astronomy were selected as experts. Ten 9th-grade students were selected as novices. Five raters were selected to score the ten experts' and ten novices' responses using the ill-structured problem scoring system. The testing procedures were the same as those of the well-structured problem scoring system. The mean difference between the expert group and the novice group was 8.72 ($p <$

.000) of ill-structured problem-solving scores. The expert group obtained higher scores than those of the novice group. The results are summarized in Table 3.11.

Table 3. 11

Comparison between Novice and Expert Groups

Group	n	<u>Well-Structured Problem</u>				<u>Ill-Structured Problem</u>			
		<u>M</u>	<u>SD</u>	t	p	<u>M</u>	<u>SD</u>	t	p
<u>Problem-Solving Tests</u>									
Novice	10	.36	.83	9.02	.000	6.2	1.43	11.60	.000
Expert	10	4.32	1.12			14.92	1.90		
<u>Justification Skill Tests</u>									
Novice	10	1.00	.86	3.70	.002	1.06	1.19	4.81	.000
Expert	10	2.58	1.04			4.44	1.88		
<u>Structural Knowledge Tests</u>									
Novice	10	1.60	1.71	3.12	.008	6.3	1.57	5.76	.000
Expert	10	5.20	3.23			18.8	6.68		

Note. n = Number of Sample. M = Mean. SD = Standard Deviation.

All of the results showed that the expert group was significantly better than the novice group. The result indicated that the scoring system can discriminate between good and poor problem solvers in an astronomy context. Consequently, the rubric systems can discriminate the differences between students who demonstrate a well-organized problem-solving process and those who demonstrate a disorganized process in given problem situations.

Scoring of the Tests

The tests were scored by a team, made up of the investigator and two trained assistants, using a marking scheme that was standardized by the research teams and experts. Each rater scored students' responses individually, based on the agreed upon scoring systems. Since raters did not know the students who took the tests, they could only score students' answers based on responses to the questionnaire rather than on personal interpretations of students. When scoring was completed, the two raters' scores were added together to derive an individual final score in the analysis. Cronbach's coefficient alpha (α) was used to estimate scorers' inter-rater reliability across the scorers. The detail inter-rater reliability is summarized in Table 3.12.

Table 3. 12

Inter-Rater Reliability between Scorers

Content		Number of Cases	Number of Items	Cronbach's Coefficient Alpha (α)
<u>Well-Structured</u>	PS	118	2	.83
	JS	118	2	.84
<u>Near-Transfer Ill-Structured</u>	PS	112	2	.85
	JS	112	2	.82
<u>Far-Transfer Ill-Structured</u>	PS	112	2	.82
	JS	112	2	.80

Note. PS = Problem Solving. JS = Justification Skills.

Procedure

The study was conducted during the months of December, 1997 and January, 1998. All instruments and questionnaires, with instructional procedures, were sent to teachers two weeks prior to administration. The teacher and students were asked to provide demographic information and complete a release form before any data was collected.

During the three weeks of science classes, all students used an Apple Macintosh computer and AV multimedia software program. They worked on an investigative research study relating to astronomy during 55-minute class periods, five times per a week. After selecting the Nearby Star research investigation, students in a team were guided by virtual mentors through the steps of scientific research: background research, data collection, data analysis, data interpretation and presentation of results.

After finishing the three weeks AV investigation, a teacher and an investigator administrated the problem-solving tests and questionnaires. Two classroom periods were used to administer the problem solving tests, HSP, TOSRA, and TMA questionnaires.

In the first classroom period, students solved two ill-structured problems. The cognitive components of ill-structured problem solving including domain-specific knowledge, structural knowledge, and justification skills, were measured as well. In the second classroom period, students' well-structured problem-solving skills were assessed, based on their experiences during the three-week AV investigation. The teacher gave each student a questionnaire relating to the Nearby Stars research path. Students answered only the questions relating to the Nearby Stars research path. As in the ill-structured problem test, domain-specific knowledge, structural knowledge, and justification skills were assessed by embedding appropriate test items. In this classroom period, HSP, TOSRA, TMA were administered to measures students' metacognition and non-cognitive variables.

Immediately after finishing the well-structured problem-solving testing, the students were asked to answer the questionnaire of HSP in order to measure how they used metacognition in course of solving problems.

In the tests, the problems were printed individually for each student. After they were distributed, the students read the introduction before being told to solve the problems. There was no time limitation to finish all the instruments. The students were permitted to spend as much time as necessary to solve the problems and answer the questionnaires. The time spent to complete all instruments is detailed in Table 3.13.

Table 3. 13

Time Schedule for Instrument Administration

Instrument	When	Time for Completion
IPSPI, CI, & JI	Post	55 min.
WPSPI, CI, & JI	Post	35 min.
Demographic Questionnaire	Post	1 min.
HSP	Post	4 min.
TOSRA	Post	14 min.
TMA	Post	2 min.

Note. Post = Post-test.

CHAPTER 4. RESULTS

The main purpose of this study was to compare the components used in well-structured problem solving and ill-structured problem solving, rather than considering any specific component prior to another in predicting of two types of problem-solving scores. Multiple regression, simultaneous regression analysis, was used to test the hypothesis that well-structured and ill-structured problem solving may demand different skills.

Simultaneous regression analysis is designed to enter all predictor variables simultaneously into the regression equation in a single step. The results show the contribution of all variables to predict the criterion variable. Therefore, the simultaneous regression analysis examines which components among all those entered are statistically significant predictors of well-structured and ill-structured problem-solving scores.

The analysis was divided into three parts: well-structured, near-transfer ill-structured, and far-transfer ill-structured problem-solving analysis. Data was organized with the use of Microsoft Excel and analyzed with the use of SPSS statistic software program. Ten research hypotheses were tested using multiple regression. The R^2 and β were tested for significance in the simultaneous regression analyses.

Results of Well-Structured Problem Solving

To detect multicollinearity among the independent variables, Pearson correlation coefficients were computed for the whole sample. Table 4.1 presents the correlations between all of the major variables in well-structured problem solving. From this table, one can deduce multicollinearity between domain-specific knowledge (DK) and structural knowledge (SK). A correlation between knowledge of cognition (KCOG) and regulation of cognition (RCOG) has a high chance of multicollinearity as well.

In order to deal with multicollinearity of DK and SK, the investigator chose the strategy of combining two highly correlated independent variables into a single variable and using the composite variable in the regression equation. Since DK and SK both measured the students' content understanding in a domain, the use of a composite variable created by combining two variables was appropriate in the analysis. The new variable created by combining the scores of DK and SK was called content understanding.

Table 4. 1

Intercorrelations among the Independent Variables in Well-Structured Problem Analysis

Variable	1	2	3	4	5	6	7
Students ($n = 118$)							
1. Domain-Specific Knowledge	---						
2. Structural Knowledge	.72***	---					
3. Justification Skills	.32***	.47***	---				
4. Attitude	.31***	.39***	.50***	---			
5. Motivation	.21*	.20*	.30***	.63***	---		
6. Knowledge of Cognition	.14	.09	.20*	.49***	.40***	---	
7. Regulation of Cognition	-.02	-.01	.12	.32***	.24**	.68***	---

Note. *** $p < .001$. ** $p < .01$. * $p < .05$.

In the case of KCOG and RCOG, the technique of using a composite of two variables was not appropriate when confronted with a possible risk of multicollinearity in the analysis, because the two variables were intended to measure two different aspects of metacognition. Moreover, since variables are thought to be important components in solving problems, two variables can not be deleted in a regression equation. As mentioned before, the study was intended to determine the important components in different types of problem solving, not to compare which component is a better predictor than other components. The KCOG and RCOG were entered simultaneously in the regression equation in order to determine their contribution in predicting of well-structured problem-solving scores.

In the first step of the analysis to determine which variables significantly predicted the well-structured problem-solving scores of the samples, all the predictor variables, including content understanding, justification skills, science attitude, motivation in astronomy, knowledge of cognition and regulation of cognition were entered into the model simultaneously. Only two variables, content understanding ($\beta = .35$, $p < .000$) and justification skills ($\beta = .35$, $p < .000$), emerged as significant predictors of well-structured problem-solving scores.

In the second step of the analysis, to reduce the error term associated with the inclusion of nonsignificant predictors in regression models, the investigator conducted a

regression that included only the significant predictors from the first regression analysis. The regression results from the final model are summarized in Table 4.2.

Table 4. 2

Summary of Simultaneous Regression Analysis for Variables Predicting Well-Structured Problem-Solving Scores (N = 118)

Variables	<u>B</u>	<u>SE B</u>	β	T	P
Justification Skills	.34	.06	.43	5.64	.000
Content Understanding	.62	.12	.38	5.04	.000
Constant	1.44	.69		2.1	.038

Note. $R^2 = .48$ ($p < .000$).

In the final model, content understanding, derived by combining domain-specific knowledge and structural knowledge, was a significant predictor of well-structured problem-solving scores. Additionally, justification skills was a significant predictor of well-structured problem-solving scores. Content understanding and justification skills accounted for 48 % ($p < .000$) of the variance in well-structured problem-solving scores.

Overall, students who had domain-specific knowledge, structural knowledge, and justification skills were most likely to achieve high scores in well-structured problems. These results showed that domain-specific knowledge, structural knowledge, and justification skills were necessary components for solving well-structured problems.

Violations of any assumptions of multiple regression analysis were checked in the overall plot and normal probability plot of residuals. In the overall plot, residuals resembled observations from a normal distribution with $M = 0$ and $SD = .99$. Residuals of the samples fell approximately on a straight line in a normal probability line. Overall results of the residual graphs indicated that the samples of this study met the assumption of multiple regression analysis and the multiple regression technique can be used to analyze the data of the well-structured problem.

Finally, the technique of cross-validation was used to determine whether the prediction equation has a chance of being successful when it is used with a new group of individuals. First, the original group of students is divided into two subgroups by randomly

selecting 50 % samples. Only one of the subgroups was used to develop the prediction equation. This equation was used to predict a problem-solving score for each person in the second subgroup. The second subgroup was not used to develop the prediction equation. The predicted criterion scores for students in the second subgroup were correlated with their actual well-structured problem-solving scores. This correlation was .67 ($p < .000$). The Multiple R of the first subgroup was .70. The differences between r and Multiple R was only .03. Additionally, the correlation was significantly different from zero, meaning that the prediction equation of well-structured problem-solving scorers works for students other than those who were used to develop the equation.

Results of Near-Transfer Ill-Structured Problem Solving

Table 4.3 presents the correlations between all of the major variables in near-transfer ill-structured problem solving. The results indicated that KCOG and RCOG, and SK and justification skills were highly correlated to each other. Although these variables had strong relationships, all of the variables were entered in a regression equation for near-transfer ill-structured problem-solving analysis.

Table 4. 3

Intercorrelations among the Independent Variables in Near-Transfer Ill-Structured Problem Analysis

Variable	1	2	3	4	5	6	7
Students ($n = 112$)							
1. Domain-Specific Knowledge	---						
2. Structural Knowledge	.34***	---					
3. Justification Skills	.35***	.86***	---				
4. Attitude	.20*	.30***	.31***	---			
5. Motivation	.20*	.16	.13	.58***	---		
6. Knowledge of Cognition	.21*	.19*	.18	.54***	.43***	---	
7. Regulation of Cognition	.11	.13	.12	.37***	.25**	.69**	---

Note. *** $p < .001$. ** $p < .01$. * $p < .05$.

Three variables, structural knowledge ($\beta = .31$, $p < .012$), science attitude ($\beta = .27$, $p < .002$), and justification skills ($\beta = .43$, $p < .000$) emerged as significant predictors of near-transfer ill-structured problem-solving scores. To reduce the error term associated with the inclusion of nonsignificant predictors in a regression model, the second regression was conducted by including only the significant predictors from the first regression analysis. The regression results from the final model are summarized in Table 4.4.

Table 4. 4

Summary of Simultaneous Regression Analysis for Variables Predicting Near-Transfer Ill-Structured Problem-Solving Scores (N = 112)

Variables	<u>B</u>	<u>SE B</u>	β	T	P
Justification Skills	1.11	.28	.46	3.88	.000
Structural Knowledge	.90	.37	.28	2.43	.017
Science Attitude	.022	.009	.15	2.42	.017
Constant	- 2.75	2.02		- 1.36	.176

Note. $R^2 = .61$ ($p < .000$)

Based on the results, students who had high scores of justification skills, structural knowledge, and science attitude were likely to get high scores in the near-transfer ill-structured problem. The three variables accounted for 61 % of the variance in near-transfer ill-structured problem-solving scores. They are important components for solving near-transfer ill-structured problems.

The data of the near-transfer ill-structured problem met the assumption of regression analysis based on the results of two residuals plots with $M = 0$ and $SD = .97$. The result of cross-validation was that the Multiple R of the first subgroup was .77. The correlation between predicted criterion scores for students in the second subgroup and actual near-transfer ill-structured problem-solving scores was .75 ($p < .000$). The correlation was significantly different from zero. It indicated that the prediction equation of near-transfer ill-structured problem-solving scores works for students other than those who were used to develop the equation.

Results of Far-Transfer Ill-Structured Problem Solving

Table 4.5 presents the correlations between all the major variables in far-transfer ill-structured problem solving. All independent variables were entered into the regression equation regardless of high relationship between the two variables, KCOG and RCOG.

Table 4. 5

Intercorrelations among the Independent Variables in Far-Transfer Ill-Structured Problem Analysis

Variable	1	2	3	4	5	6	7
Students ($n = 112$)							
1. Domain-Specific Knowledge	---						
2. Structural Knowledge	.22*	---					
3. Justification Skills	.000	.28**	---				
4. Science Attitude	.36***	.21*	.06	---			
5. Motivation	.24**	.03	-.04	.58***	---		
6. Knowledge of Cognition	.19	.19*	-.03	.54***	.43**	---	
7. Regulation of Cognition	.18	.11	-.15	.37***	.25**	.69***	---

Note. *** $p < .001$. ** $p < .01$. * $p < .05$

In the first step of the analysis, all the predictor variables, including domain-specific knowledge, structural knowledge, justification skills, science attitude, motivation in astronomy, knowledge of cognition, and regulation of cognition were entered into the model simultaneously. Three variables, including justification skills ($\beta = .32$, $p < .000$), structural knowledge ($\beta = .50$, $p < .000$) and regulation of cognition ($\beta = .26$, $p < .013$), emerged as significant predictors of far-transfer ill-structured problem-solving scores. The regression results from the final model including only the significant predictors from the first regression, are summarized in Table 4.6.

Table 4. 6

Summary of Simultaneous Regression Analysis for Variables Predicting Far-Transfer Ill-Structured Problem-Solving Scores (N = 111)

Variables	<u>B</u>	<u>SE B</u>	β	T	P
Justification Skills	.49	.12	.32	4.30	.000
Structural Knowledge	2.72	.41	.48	6.57	.000
Regulation of Cognition	.26	.10	.20	2.70	.008
Constant	4.05	1.87		2.17	.032

Note. $R^2 = .47$ ($p < .000$)

In the final model, justification skills, structural knowledge, and regulation of cognition were significant predictors of far-transfer ill-structured problem-solving scores. These three variables accounted for 47% of the variance in far-transfer ill-structured problem-solving scores.

Overall, the results indicated that students who had good structural knowledge, regulation of cognition, and justification skills were most likely to achieve high scores in a far-transfer ill-structured problem. These results showed that structural knowledge, regulation of cognition and justification skills were critical components for solving far-transfer ill-structured problems.

Overall plot and normal probability plot of residuals were examined to check the violation of assumption of multiple regression analysis. The results of residual graphs examined showed that the samples of far-transfer ill-structured problem met the assumption with $\underline{M} = 0$ and $\underline{SD} = .97$ and the multiple regression technique can be used to analyze the far-transfer ill-structured problem data.

In the results of cross-validation, the correlation between the predicted criterion scores for students in the second subgroup and their actual far-transfer ill-structured problem-solving scores was .68 ($p < .000$). The Multiple R of the first subgroup was .69. The correlation indicated that the prediction equation of far-transfer ill-structured problem-solving scores works for students other than those who were used to develop the equation.

Summary of Results

The results supported the research hypotheses of domain-specific knowledge and structural knowledge as significant predictors of well-structured problem-solving scores. However, metacognition, especially knowledge of cognition, was not a significant predictor in well-structured problem-solving scores. Although justification skills was not included in the research hypothesis, it was a strong predictor of well-structured problem-solving scores.

In ill-structured problem-solving analysis, near-transfer ill-structured problem-solving scores were predicted significantly by justification skills, structural knowledge, and science attitude variables. As in well-structured problem-solving analysis, neither knowledge of cognition nor regulation of cognition were strong predictors in near-transfer ill-structured problem-solving scores. Additionally, domain-specific knowledge and motivation in astronomy were not statistically significant predictors.

Justification skills, structural knowledge, and regulation of cognition were strong predictors in far-transfer ill-structured problem-solving scores. Domain-specific knowledge, science attitude, motivation in astronomy, and knowledge of cognition were not supported as statistically significant predictors of far-transfer ill-structured problem-solving scores.

CHAPTER 5. DISCUSSION

The results of the present study support the hypothesis that well-structured and ill-structured problems require different components for reaching successful solutions (Jonassen, 1997; Reitman, 1965; Sinnott, 1989; Voss & Post, 1988; Wilson & Cole 1992). In the overall results, domain-specific knowledge, structural knowledge, and justification skills were powerful predictors of well-structured problem-solving scores. Ill-structured problem-solving scores were significantly predicted by structural knowledge, justification skills, attitude, and regulation of cognition.

This chapter is divided into two sections, well-structured and ill-structured problem solving, to discuss in depth the result of the study. In each section, significant predictors of each problem type are examined intensively in comparison to the research hypotheses of the study. This comparison is necessary to illustrate the discrepancy between problem-solving theories and the result of this investigation, and to explore potential reasons that the hypotheses were not supported by the results.

Finally, implications for science education in a multimedia simulation environment, assessment on problem solving, and problem-solving research are presented.

Well-Structured Problem Solving

This investigation showed that highly correlated domain-specific knowledge and structural knowledge were powerful predictors of well-structured problem-solving scores. These findings are consistent with the hypothesis that students' domain-specific knowledge and structural knowledge may be important components in solving well-structured problems. It was speculated that students who understood basic concepts, facts, and principles in a well-organized way could reach a solution by retrieving the knowledge without restructuring it to apply new problem situations. The results support the theory that students who possess an appropriate, well-organized knowledge base are able to solve the problem directly because they recognize each problem from a previous experience and know which moves are appropriate (Chi, et al., 1981; Glaser, 1989).

Although it was not hypothesized to be an important component, justification skills was shown to be a strong predictor in well-structured problem solving. The results indicated that if students can provide logical arguments of their opinion in a given situation, they may successfully solve well-structured problems in the same subject matter domain as

well. This result, however, has a discrepancy with the theory of well-structured problem solving. Research of well-structured problem solving proposed that, since well-structured problems have a unique correct answer, they do not require a justification of the answer in solving processes. The inconsistent finding that justification skills is a significant predictor may be caused by the strong relationship between justification skills and well-organized knowledge structure.

The correlation matrix showed that justification skills in well-structured problems had significant relationships with both domain-specific knowledge ($r = .32$) and structural knowledge ($r = .47$). Moreover, content understanding variable was a significant predictor ($\beta = .31, p < .000$) in the regression equation of justification skills using the five predictors including content understanding, science attitude, motivation in astronomy, knowledge of cognition, and regulation of cognition. It supported the evidence that a well-organized knowledge structure may critically influence the development of logical arguments such as those used in solving the well-structured problems. These findings support the speculation that justification skills was a significant predictor of well-structured problem-solving scores because of this interrelationship.

Alternately, knowledge of cognition (e.g., general strategies) was not supported as a strong predictor in well-structured problem solving. A potential reason for this non-significant result could be the integration of the powerful predictors of domain-specific knowledge and structural knowledge. Since content understanding is essential for solving well-structured problems, knowledge of cognition may not be sufficient unless solvers have an appropriate level of content understanding. This finding supported the previous research that the puzzle-like structure of knowledge-free problems has limited application in domain-dependent problems (Atwood, et al., 1980; Greeno, 1974). Unlike knowledge-free problems, well-structured problems require the acquisition of large bodies of content knowledge. These general strategies are not useful in finding a solution without appropriate well-organized knowledge in subject matter domains (Gick, 1986).

Furthermore, the results indirectly showed that students who possess well-organized knowledge relevant to problems may rarely engage in a general searching process (Gick, 1986). A rich knowledge base in subject matter domains affords students the successful solution without the use of general strategies. If the students have previous experience with a specific type of problem, they are able to activate a correct schema from their memory and immediately solve the problem without using general strategies (Chi, et al., 1981; Gick, 1986).

General strategies may serve as a guide in the well-structured problem-solving process. They may not, however, guarantee a solution without engaging well-organized knowledge structure (Mayer, 1983). Therefore, the knowledge of students, organized into structures, may allow for the effective use of general strategies as well as directly afford a successful solution without using general strategies.

The overall results from well-structured problems supported well-organized knowledge structure and justification skills as powerful predictors. Attitude, motivation, knowledge of cognition and regulation of cognition were not strong predictors of well-structured problem-solving scores. When they are not engaged in a well-organized knowledge structure, knowledge of cognition, attitude, motivation, and regulation of cognition have constraints for solving well-structured problems. In addition, it is not necessary to use regulation of cognition and non-cognitive variables if students have sufficient knowledge structure in a particular subject matter domain.

In conclusion, if students possess appropriate schematic-driven knowledge, they can directly solve the problem without searching for a solution using various general strategies, regulation of cognition, and non-cognitive variables. Complete understanding of content knowledge is critical in solving well-structured problems. Cognition, including domain-specific knowledge and structural knowledge, and justification skills are necessary component for solving well-structured problems.

In this section, the results of well-structured problem solving were discussed and the important role of content understanding was shown. In the following section, the results of ill-structured problem solving are discussed and compared to those of well-structured problem solving.

Ill-Structured Problem Solving

This discussion concentrates on the significant predictors of ill-structured problem-solving scores. Additional investigation, beyond that originally proposed, was conducted to learn why the original hypotheses were not supported by the results.

Cognition

The findings from the two ill-structured problems supported the hypothesis that students' structural knowledge is a powerful predictor. However, domain-specific knowledge was not a strong predictor of ill-structured problem-solving scores. It was apparent that successful ill-structured problem solving was dependent on how domain-specific knowledge is structured.

Although the two ill-structured problems required the use of conceptual scientific knowledge that was taught in classes, they were structurally unfamiliar to the students (Egan & Greeno, 1974; Robertson, 1990). Unlike well-structured problems, students' knowledge obtained from their prior experiences had to be reorganized around fundamental principles. It was not sufficient for them to deduce and retrieve information from memory. Therefore, domain-specific knowledge itself may be a constraint for reaching a satisfactory solution in ill-structured problems.

The correlation matrix had shown the limitation of domain-specific knowledge in ill-structured problem solving by comparing those of well-structured problems as well. In ill-structured problems, the correlation between domain-specific knowledge and structural knowledge ($r = .34$ and $r = .22$) was much lower than those of well-structured problems ($r = .72$). Unlike the well-structured problems, the correlational evidence indicated that students who achieved high scores in domain-specific knowledge may not always perform well in structural knowledge. Structural knowledge requires more cognitive skills than those of domain-specific knowledge in ill-structured problems.

In sum, students' knowledge structure is a critical component in solving ill-structured problems. Students who depend on facts, concepts, and rules from their memory do not perform as well on transfer ill-structured problems as do students who rely on an understanding of the deeper structure. To reach a successful solution, the domain-specific knowledge must be organized appropriately and applied in various problem situations. Thus, domain-specific knowledge, by itself, has constraints for solving ill-structured problems.

Metacognition

Knowledge of cognition, including information-selection and problem-solving strategies, was not a significant predictor in near-transfer or far-transfer ill-structured problems. As with well-structured problems, results indirectly indicated that although some general strategies can theoretically be used across several domains, their success may depend upon the adequacy of the knowledge structure to support the strategy (see Polson & Jeffries, 1985). As mentioned in well-structured problems, the use of general strategies may be limited by the capacity of the knowledge base in which it is being applied. If students do not have an adequate knowledge of the problem domain, their general strategies may fail to solve problems.

In addition, in the results presented here, it was apparent that although students possess useful general strategies, they may not apply them in appropriate situations unless they have knowledge about when and why to use them. Since there are no clear-cut rules to govern the use of general strategies in complicated ill-structured problems, students have to control and evaluate the use of these strategies, depending on problem situations and solving processes. Without knowing when and why to use general strategies, students may not use them effectively or appropriately in new situations to reach successful solutions.

Alternatively, regulation of cognition, including planning and monitoring skills, was a strong predictor in solving a far-transfer ill-structured problem. It is consistent with the hypothesis that regulation of cognition is a critical component for solving ill-structured problems. The far-transfer ill-structured problem situation required the consideration of alternative goals as well as the handling of competing goals. Students must demonstrate their cognitive endeavors in different ways rather than coping with a problem in a straightforward manner. Because of the uncertain problem situation, students need to use the monitoring and planning process to keep track of the solution activity, noting their limitations, and the effects of their efforts.

However, regulation of cognition was not a significant predictor in a near-transfer ill-structured problem. The result suggests that the near-transfer ill-structured problem may not be complicated enough to challenge students to use regulation of cognition to reach a successful solution. In the near-transfer problem, the goals and action alternatives were rather stable throughout the decision-making process, even though students had to consider various perspectives. For instance, in the near-transfer ill-structured problem, an astronomical emergency situation asked students to select appropriate team members

without providing any constraints. Since there were no specific limitations such as budget, time, and social issues during the solving processes, students were able to choose as many team members as they needed. Although the problem has many alternative solutions and perspectives, they were permitted to select solutions and perspectives without considering competing goals.

Moreover, regarding the astronomical emergency problem, students might have been exposed previously to the subjects of the study from articles, movies, or TV programs. The problems may lack the conceptual and structural complexity necessary to encourage and challenge students to reflect on their problem-solving process. The familiarity of the contents may allow the students to solve the problems without planning solving processes and monitoring their own cognitive efforts. Thus, the students may not find it necessary to use regulation of cognition in solving processes of the near-transfer ill-structured problem.

The results surmised that students are encouraged to use the regulation of cognition when problems are sufficiently complicated to challenge them. For solving complicate ill-structured problems, the students must possess not only the necessary knowledge but also regulation of cognition, including modifications of plans, reevaluation of goals, and monitoring of one's own cognitive efforts. If the problem is not structurally complicated enough, the students may not use their regulation of cognitive skills even though they possess them.

Non-Cognitive Variables

Science attitude was a strong predictor in a near-transfer ill-structured problem. The nature of the near-transfer ill-structured problem in the study required students' general scientific principles and concepts, not limited only those obtained from the three weeks of instructional periods. Students had to choose suitable team members in a given problem statement based on their value, belief, and attitude. The results indicate that attitude, value, and belief toward science influence students' selection of team members in a more scientific way.

However, motivation in astronomy was not a significant predictor in the near-transfer ill-structured problem. The near-transfer ill-structured problem required general scientific knowledge including physics, mathematics, chemistry, geology, meteorology, as well as astronomy. Motivation in astronomy may not be sufficient to solve the problems

unless students have high motivation in other science subjects. The other interpretation is that the correlation between science attitude and motivation in astronomy was high ($r = .58$). There may be redundancy in measuring processes of the two variables. The two variables may possess the same construct, non-cognitive variables toward general science. In a regression analysis, a potential multicollinearity problem might exist.

In the far-transfer ill-structured problem, the hypothesis did not assume that both science attitude and motivation in astronomy were powerful predictors. In contrast to the near-transfer ill-structured problem, the nature of the far-transfer ill-structured problem provided necessary information in the problem statements. Students must choose their solution by comparing given information. It required students' general reflective judgmental skills outside the boundary of science. The students had to consider multiple perspectives including budgetary, human life, environment, geography, and future trends that were not directly related to science. When the students decide the goals or essence of the problems, they may use their affect, emotion, value, and belief relating not only for science but also for all components of the problem situation.

Although students may not have strong positive attitude, value, and belief toward science, they may be encouraged to continue the solving process by a strong internal effective reward from the other issues in the problem. The non-cognitive variables of the other issues may motivate the students to persist in the solution effort and maintain awareness of the problem to continuously search for information that is potentially relevant to the problem.

In solving ill-structured problems, students need broad and global experience with the object, events, or idea. Using various problem situations, the students must be encouraged to think of global impacts by integrating all of the issues. Since ill-structured problems contain large amounts of knowledge in various domains, students' non-cognitive variables must be considered in a variety of ways, not only with regard to subject areas.

Justification Skills

In both of the ill-structured problems, the results supported the hypothesis that justification skills is a strong predictor. In this investigation, successful ill-structured problem solvers constructed logical arguments to support their chosen solution. Although the degree of justification skills was somewhat different, most students provided arguments of their final solution based on their goals or perceptions of the nature of the problems.

These results satisfied the theory that successful ill-structured problem solvers should justify their decision to provide warrants for their own interpretations and judgments because ill-structured problems have many potential solutions (Jonassen, 1997; Voss & Post, 1988). Overall, justification skills is an essential component for solving ill-structured problems.

In addition, the surprising result of the study was the determination that there was no relationship between justification skills and domain-specific knowledge in a far-transfer ill-structured problem.

For deeper understanding of this result, additional investigation was conducted on students' justification skills. In ill-structured problem solving, the solver should provide logical evidence, including both the preferred and rejected perspectives, for constructing successful arguments. In this study, students who formed an argument by considering both preferred perspectives and rejected alternative perspectives, received a higher score than those who considered only one of perspectives.

Students' argument patterns were categorized based on their domain-specific knowledge and structural knowledge. There were generally three argument patterns, such that students justified their preferred solution by providing benefits of their solutions, limitations of alternative views, and alternative suggestions to overcome minor drawbacks of their solutions.

Students who possessed a well-developed structural knowledge base might construct their arguments including at least two patterns. For instance, the students provided benefits of their solution and limitations of other solutions, or benefits of their solution and alternative suggestions to overcome a minor limitation of their solution. However, students who lacked a deeper knowledge structure might concentrate on only one perspective within the domain knowledge. These students constructed arguments by merely providing benefits of their preferred solution. They did not consider other alternative views for constructing more defensible arguments.

The additional investigation speculates that their surface content understanding makes students' perception focus on a particular view rather than examine possible alternative perspectives. Thus, their arguments may emphasize a perspective within the boundary of their domain-specific knowledge.

Implication

A central concern of this study was the investigation of necessary components for solving well-structured and ill-structured problems in open-ended, multimedia simulation environments. There are several important implications of this research project for facilitating problem-solving skills in instructional settings. This section discusses some of the specific design features of problem solving, problem-solving instruments, and includes a general consideration of problem-solving research.

Pedagogical Implication on Problem Solving

The results of this study have important implications for instructional practice, especially science education in a multimedia simulation environment. The overall results of the investigation illustrated that ill-structured science problems have different solving processes and components as compared to those of well-structured science problems. Therefore, in order to promote students' science problem-solving skills, science educators must develop teaching and learning standards and strategies using different principles which depend on the specified educational goals and the nature of problems.

To improve learners' well-structured problem-solving skills, instructions must focus on enhancing learners' cognitive skills including domain-specific knowledge and structural knowledge in subject matter domains. Instead of merely memorizing concepts, rules, and principles, students should be taught ways in which their available knowledge can be recognized and manipulated by integrating the new content knowledge in a meaningful way (Mayer, 1974; Mayer, et al., 1975). That is, instructional strategies must be developed to facilitate students' structural knowledge, including stored coherent chunks of the information that enable them to access meaningful patterns and principles rapidly if necessary (Chi, et al., 1981).

A number of strategies have been developed to enhance students' structural knowledge such as conceptual models (Mayer, 1989), and concept mapping (Novak, 1984) (see more detail Gick, 1984; Jonassen, 1997). Instructional designers should appropriately apply and effectively redesign available strategies to facilitate students' structural knowledge to promote the well-structured problem-solving process in a multimedia simulation environment.

Alternatively, students must promote metacognition, non-cognitive variables, justification skills and cognition for solving ill-structured problems. In order to enhance these skills, the problem tasks must be developed in an authentic, complicated way including multiple perspectives and problem constraints. Well-developed complicated ill-structured problem tasks are only able to encourage the students to reflect on their solving process using their metacognition, non-cognitive variables, justification skills, and cognition.

Therefore, instructional designers must put considerable effort into developing challenging authentic problem tasks similar to those faced in real world situations. In addition, students should understand that everyday problems can be solved in many ways depending on their perception of the multiple perspectives of the problems. Moreover, the students need to comprehend the divergent perspectives which influence each other in the problem situation, can be changed depending on problem situations, and must be negotiated in order to find an optimal solution. Thus, effective instructional strategies such as the cognitive flexibility theory (Spiro, et al., 1987, 1988) must be implemented to let students perceive the multiple perspectives within various problem situations.

Finally, ill-structured problem solving can be considered a judgmental thinking process in which one of the various possible solutions is chosen by considering arguments of other opposing assumptions in problem situations (Churchman, 1971). Therefore, students should be able to support arguments for their preferable solution by articulating the different assumptions (Jonassen, 1997). The instructional designers should create rich learning environments to develop the students' abilities to argue for their solutions or decisions. Although proven and effective strategies for enhancing justification skills are lacking, modeling and coaching argumentation have been developed by providing an argument template or argument checklist to scaffold students' justification skills (Jonassen, 1997).

Assessment Implication on Problem Solving

It seems clear that this investigation is bringing forth information that has important implications for assessment in problem solving as well. Because of the differences in solving processes and components, science educators must develop different teaching and learning standards as well as a different assessment framework depending on the type of problem solving. On the basis of the results, structural knowledge must be included in a conceptual framework for assessing well-structured problem-solving skills. In addition to

structural knowledge, justification skills should be selected to be the focus of assessing ill-structured problem-solving skills.

Psychologists investigating cognitive theories of learning and memory have developed assessment instruments that measure students' knowledge structures. Various indirect methods have been suggested to indicate the knowledge structure that exists in an individual student's mind, using techniques such as drawing concept maps, classification or generation of example concepts, or explanation of interrelationships between example concepts (see detail Jonassen, et al., 1993). Using the available techniques for measuring knowledge structure, designers are able to modify them in order to assess important aspects of structural knowledge which will result in desired learning outcomes. Students' scores obtained from structural knowledge instruments can be used to predict their problem-solving skills in a particular domain,

Additionally, these various techniques of assessing structural knowledge may surmount some limitations of the current problem-solving assessment instruments. Educators have developed a framework for assessment instruments that measures students' problem-solving skills. The focus of their efforts has been the construct domain, assessment task specifications and scoring rubric specifications, focusing on the depth of construct domains (Royer, et al., 1993). These efforts have been explicitly delineated to ensure that the tasks and scoring rubrics reflected the breadth of the construct domain. These constraints have questioned the validity of the problem-solving instruments.

Methods for assessing structural knowledge can be suggested indirectly, measuring problem-solving skills concerning both the depth and breadth of the construct domain. Since the result of the investigation found that problem-solving skills are strongly related to structural knowledge, it can be used as an indicator of problem-solving skills to measure the depth of the construct domain. Furthermore, the nature of measuring structural knowledge requires deeper conceptual understanding in a broad content domain along with integrating the concepts in meaningful structural properties. Thus, assessment instruments of structural knowledge can measure students' depth of understanding in a broad construct domain.

Additionally, a number of methods for measuring students' knowledge structure can be designed in a variety of test formats that are scored in more reliable ways than those of open-ended essay questions. Using several different formats, structural knowledge can be measured repeatedly to get students' true scores. The set of scores obtained from those test formats may be used to illustrate with reliability students' problem-solving skills by

promoting the critical validity problems of the currently available problem-solving instruments.

Unlike those of structural knowledge, approaches to assess justification skills are rarely found in spite of its' important role in problem-solving processes. From the results of the study, justification skills play a critical role as one of multiple indicators of problem-solving skills. Students' justification skills can be provided as an additional evidence of construct validity to overcome the shortcomings of the current problem-solving instruments. Therefore, more studies should be attempted to assess students' justification skills using various techniques including asking students to justify their decision; to think aloud as they develop arguments to reach the conclusion.

Research Implication on Problem Solving

The results of this investigation also suggest some issues that seem particularly fruitful to explore. One set of issues centers around the role of domain-specific knowledge in ill-structured problem solving. It was noted earlier that domain-specific knowledge is a primary factor in solving ill-structured problems (Jonassen, 1997; Voss, 1991). However, the conclusion of this study is expected to encourage more research that investigates an emphasis on domain-specific knowledge in ill-structured problem solving.

Unlike the theories relating to problem-solving skills, domain-specific knowledge was not a critical component of either near-transfer or far-transfer ill-structured problems. The results presume domain-specific knowledge in a particular subject directly prompts students to see only a perspective within their domain-knowledge rather than to consider multiple perspectives in problem situations. The students' domain knowledge makes their solving processes focus within a particular content area. Thus, the students may employ linear well-structured solving process by retrieving concepts, rules, or principles from their memory to solve ill-structured problems which require a dynamic ongoing solving process.

Additionally, their arguments may emphasize a perspective within the boundary of their domain-specific knowledge rather than articulating opposing assumptions in problem contexts. That is, the student perceives a given ill-structured problem as a well-structured problem. They adopt linear well-structured problem solving processes for solving ill-structured problems.

More research should explore the limitation of domain-specific knowledge in solving ill-structured problems using well-developed and proven assessment instruments for

measuring domain-specific knowledge. For instance, the researcher needs to select students who have high scores in domain-specific knowledge but not in structural knowledge. The students' solving process and argument patterns must be precisely analyzed to obtain the major shortcoming of domain-specific knowledge in solving ill-structured problems.

The other set of issues to be explored relates to knowledge of cognition in problem-solving skills. The conclusion of this study calls for a reevaluation of our understanding of the knowledge of cognition and of our present theory of general strategies. In a very general sense, domain-independent general strategies such as information-selection and problem-solving strategies are useful to solve problems when solvers fail to find appropriate schematic driven knowledge within their memory. It would appear, however, that general strategies did not have a significant relationship with any type of problem solving. This result should be investigated carefully in further research.

Potential inferences to be drawn from the data include how students interpret the general strategies presented by the inventories. Although students used some useful strategies in the solving process, they may not match the words in inventory with their actual behaviors because the questions are not clear. Future research should be conducted to determine the discrepancy between actual and reported behavior, and the relationship between actual behaviors and problem solving. For instance, questions asked of students must be worded very carefully. In addition, researchers observe students' solving processes to learn whether they use some general strategies to help them understand the problem. The students' observable behaviors should be compared with their reported behavior on related general strategies question items.

The other inference drawn from the lack of a significant relationship between problem-solving skills is that there may be clear differences between understanding general strategies, how to use them, and when and why to use them. Diagnostic assessment of general strategies and skills should be conducted to identify students who understand the concepts of general strategies but lack knowledge of procedures to apply them, and students who can perform procedures correctly but do not know when and why it is appropriate to apply them. Thus, three aspects of general strategies can be distinguished and related to problem-solving skills: understanding of general strategies, knowing the procedures for conducting them, and knowing application conditions of them. The three aspects should be analyzed separately to determine which aspect of general strategy has a significant relationship with problem-solving skills.

Secondly, the importance of regulation of cognition in the present study should be investigated in the near future as well. The complexity of ill-structured problem tasks may interact with the use of regulation of cognition. The study using a complicated task found that regulation of cognition was significantly related to achievements, whereas the study using a less complicated task did not find a significant relationship. One explanation for this inconsistent result may be that regulation of cognition may be encouraged to reflect on the problem-solving process when students work high level complexity ill-structured problem tasks. Thus, a future study should compare the students' regulation of cognition in differing degrees of complex ill-structured problem tasks.

Finally, future empirical research should explore whether the results concerning ill-structured problem solving found in this study generalize to other kinds of ill-structured domains. The content of this study was general science within an astronomy context. Additional studies of different disciplines such as political science, environmental issues, or social studies should examine whether the results are consistent with those of this study.

Summary of Discussion

This investigation was conducted to verify past research conclusions that well-structured and ill-structured problem solving require different necessary components for reaching successful solutions. This study has found that the two problem types definitely require different components.

In well-structured problems, cognition, including domain-specific knowledge and structural knowledge, is a necessary component in solving well-structured problems. Justification skills, which was highly correlated with domain-specific knowledge and structural knowledge, is an essential component as well. However, knowledge of cognition, regulation of cognition, science attitude, and motivation in astronomy are not critical components in well-structured problem solving.

Alternatively, metacognition, non-cognitive variables, justification skills plus cognition were found to be essential components needed to solve ill-structured problems. In cognition, domain-specific knowledge must be organized in meaningful structural properties to activate it in appropriate situations. Thus, only structural knowledge is a critical component in ill-structured problem solving.

Moreover, regulation of cognition is important for solving ill-structured problems that are complicated and contain novel situations. In contrast, knowledge of cognition is not a necessary component unless appropriate knowledge structure in a particular domain is also possessed. Furthermore, science attitude is a critical component for solving only a near-transfer ill-structured problem. Motivation in astronomy is not a necessary component for solving ill-structured problems, as evidenced by this study. Since ill-structured problems require large amounts of content knowledge in various subjects, all non-cognitive variables relating to problem situations must be considered for successful solving processes. In summary, structural knowledge, regulation of cognition, science attitude, and justification skills are critical components for solving ill-structured problems. Domain-specific knowledge, motivation in astronomy, and knowledge of cognition are not necessary components.

It is hoped that this research will stimulate further investigation into instructional strategies to promote students' ill-structured problem-solving skills in a wide range of multimedia simulation environments.

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