PROMOTING YOUNG ADOLESCENTS' HYPOTHESIS-DEVELOPMENT PERFORMANCE IN A COMPUTER-SUPPORTED AND PROBLEM-BASED LEARNING ENVIRONMENT

A Dissertation

by

HYE JEONG KIM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2008

Major Subject: Educational Psychology

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Approved by:

Chair of Committee,	Susan Pedersen
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ABSTRACT

Promoting Young Adolescents' Hypothesis-Development Performance in a Computer-Supported and Problem-Based Learning Environment. (May 2008)

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M.Ed., Korea National University of Education

Chair of Advisory Committee: Dr. Susan Pedersen

In the study, young adolescents' hypothesis development in a computer-supported and problem-based learning environment was examined in terms of two empirical studies. The first study examined the effect of metacognitive scaffolds to strengthening hypothesis development as well as the influence of hypothesis development in the promotion of young adolescents' problem solving performance in an ill-structured problem solving environment, *Animal Investigator*. Data was collected from sixth grade students (N = 172). The findings of the study indicated that participants using metacognitive scaffolds attained significantly higher hypothesis-development performance. Results also revealed that the hypothesis-development performance showed the predictive power of the solution development performance.

In the second study, the researcher examined three factors, motivation, metacognition, and prior domain knowledge, as a predictor for children's hypothesis-development performance in the problem-based learning environment. A hypothesized model was evaluated using structural equation modeling, which is a statistical method of causal relationships. Data were collected from sixth grade students (*N* = 101) in treatment groups. Two significant factors toward children's hypothesis-development performance in an ill-structured problem solving environment were determined: Prior domain knowledge and metacognition.

Implications and limitations of the present study and issues including the experimental design are discussed.

DEDICATION

To my mother and father for their continuous love, sacrifice, and encouragement throughout my educational endeavors

ACKNOWLEDGEMENTS

I waited to write acknowledgements in my dissertation for a very long time. It is so difficult to name and express my appreciation to all the people who encouraged me during this long journey. I will certainly not forget their thoughtful encouragement and support for the rest of my life.

I would like to express my deepest appreciation to my committee chair, Dr. Susan Pedersen, for her professional support and patience for my doctoral journey. Her comments always encouraged me to use more reflective and careful considerations, as becoming to a professional. I would also like to thank Dr. Loving, Dr. Willson, and Dr. Griffing, for their guidance and support throughout the development of this dissertation. Special thanks to Dr. Lauren Cifuentes and Dr. Ronald Zellner who provided so much assistance and insight in my doctoral course work.

This journey began with the encouragement I received from three professors' to pursue my doctorate nine years ago. I would like to thank Dr. Pyung Kuk Jeon, Dr. Hanook Cho, and Dr. O-Ryong Kwon. If their encouragement had not been given, I am sure I would never have begun this journey. Also, I would like to express my deepest appreciation to Dr. Sangil Choi, Dr. Tae-Young Kim, and Tae-Uk Lee.

I would especially like to thank to my friends at Texas A&M University: Rui Kang, Tuifen Chen, Seong Ae Yu, and Woo Jin Lee.

Special thanks to my previous roommate, Amelia Coffman, her parents, Suzanne Coffman and Jimmy Coffman, and Libby Sykora. They are generous, genius, and an incredible family. Every wonderful experience in Texas came from this family.

I would especially like to thank my former and current academic advisors, Carol Wagner and Kristie Stramaski. Whenever I had questions or interests, they always listened, helped passionately, and continuously supported me.

Maybe, a person who has friends that truly believe and encourage, is a really happy person in the world. I feel that is me. I would also like to thank to my friends in Korea, Hye Young Jo, Ji Hye Lee, Kyung Hee Kang, Hee Seo Choi and her husband, Ju Young Lee, Hyun Jeong Lee, Hae Young Kim, Hye Jeong Park, and Sang Ha Lee.

I would like to express my thanks to the staff in the International Student Services who constantly encouraged me: Two bosses, Bill Taylor and Eunice Overton, Amy Winn, Kristina Reyes, La Crecia Francis, Aline Lovings, and Sherran Johnson.

I offer heartfelt thanks to many people for this dissertation, Sun Taek You, Hyun Jeong Im, Hye Jeong Seo, Dr. Hong Rae Kim and his wife, Jeong Mee Min, Suk-Sa elementary school teachers, principals, parents, and students, Ji Ryang Chung, So Young Kwon, teachers in a Il-san elementary school, Jeong Mi Je, and Ms. Tura King.

Finally, I would like to express my deepest thanks to my mother and father for their encouragement, to my grandmother, to great-grandmother in heaven, to my brothers, Sang Woo Kim and Sang Euk Kim, to my best friend Kyung Jin Oh and her husband Jeong Hoon Yu, and to Suk Hyung Hong, who always believed in me and supported my efforts.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The investigation of the processes and characteristics of problem solving has yielded a great deal of progress over several decades. Particularly, we could see increasing research interests in problem solving strategies from well-structured problems to ill-structured problems in the educational field during the last fifteen years. In general, when the initial representation of the problem is not able to lead to a solving procedure, a problem is considered as ill-structured. Hoc (1988) asserted that understanding ill-structured problem solving is a gradual affair in that a series of problem restructurings must occur. In terms of this procedure, a problem solver gradually modifies and defines his or her problem spaces, in which all the possible states are represented. Sternberg (2006) also described that ill-structured problems have no clear, readily available paths to solution. In summary, the degree of structure in problem solving is whether or not the initial state, the goal state, the permissible operators, and the path constraints (Chi & Glaser, 1985; Proctor & Dutta, 1995) are defined or structured.

However, the characteristics of ill-structured problems do not present apparent features to educate young problem solvers. The following characteristics of ill-structured problems make it difficult to educate young problem solvers about the problem-solving strategies. Researchers revealed the characteristics of ill-structured problems that make

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This dissertation follows the style of *Educational Technology Research and Development.*

solutions hard to identify, such as uncertainty of the initial state, the goal state, the operators, the path constraints to solve the ill-structured problems, and considering inconsistent data (Abelson & Levi, 1985, Adsit & London, 1997; Jonassen, 1997; Joseph & Patel, 1990; McKenzie, 1998; Proctor & Dutta, 1995). For an educator, these features create difficulties to developing effective problem solving strategies.

In well-structured problem solving, a fundamental strategy is to decompose the structure into subcomponents, or steps to solve, and this will lead to the solution of the problem at hand (Sternberg, 2006). For this, there are a number of problem-solving skills that have been developed for solving well-structured problems. However, problem-solving strategies in ill-structured problems are still not well understood and of great interest today. One approach to develop problem-solving strategies regarding ill-structured problems may be examining the role of hypothetical thinking in the process of problem solving because the hypothesis development process is thought of as a typical strategy for ill-structured problems (Johnson, 1989; Reitman, 1964). Researchers proposed that hypothesis development, including hypothesis generation and evaluation, could be one of the key activities to reduce the uncertainty of problems (Abelson & Levi, 1985; Adsit & London, 1997; Ge & Land, 2004; McKenzie, 1998; Nowell & Simon, 1972). In common life, we often confront problem situations for which we have to find a solution. We may engage in a reflective activity to solve the situation using hypotheses, which may also be called hunches, guesses, ideas, or insights (Hullfish & Smith, 1961). The simple, basic concept of hypothesis is that all hypotheses are tentative solutions to problems which can give direction to human inquiries, as well as being a product of a universal and constant human activity (Wenham, 1993). The purpose of using hypotheses in ill-structured problems is to lead the problem solver to new knowledge in that the problem solver will expect to move from suggestions which are uncertain, to information which is more reliable in terms of the testing process (Feibleman, 1972).

However, with regard to the hypothesis generation and evaluation behavior of novice, researchers have pointed out some difficulties with developing hypotheses by novice problem solvers. When people generate a hypothesis, it has been shown to be an impoverished hypothesis set in the aspects of quantity and quality. In other words, the process of hypothesis development that stands out conspicuously is that problem solvers do not try to generate various hypotheses before testing a hypothesis; they also overestimate the completeness of their hypothesis sets (Adsit, 1988; Adsit & London, 1997; Gettys & Fisher, 1979; Gettys, Mehle, & Fisher, 1986; Quinn & Alessi, 1994). Particularly, novice problem solvers show patterns in hypothesis development, such as confirmation bias, a type of cognitive bias; the tendency to only try to seek out evidence that is consistent with their hypothesis, instead of attempting to disprove it during the hypothesis development process; mechanization of thought, prior experience and knowledge result in a reluctance to investigate alternative procedures for a novel task (Anderson, 2000; Bassok & Trope, 1984; Dunbar & Fugelsang, 2005; Farris & Revlin, 1989; Klayman & Ha,1987; Luchins, 1942; Trope & Bassok, 1982; Proctor & Dutta, 1995).

These difficulties of novice problem solvers may be compensated for to some extent through metacognitvely engaging in the developing process. A metacognitive approach may be important because it provides ways to overcome the above-described issues of novice problem solvers. A novice problem solver who is highly regulated would be more perceptive of the need for hypothesis strategies, and would more likely be monitoring the usefulness of their hypotheses development.

In the present study, a two-fold approach was considered to understand enhancing young adolescents' hypothesis-development performance in ill-structured problem solving: facilitating youths' performance using metacognitive scaffolds in the computer-supported and problem-based learning module, and confirming psychological factors to predict students' performance.

PROBLEM STATEMENT

Based on the results of previous studies, novice problem solvers in ill-structured real-world problem situation have difficulties in developing hypotheses which have been thoughtfully considered along with many concurring factors to explain the given problem. Deficiencies during the hypothesis development process may cause novice problem solvers to produce poor solutions. Metacognitive strategies in learning and problem solving have been recognized as an important factor that enhances the perception of efficacy and ability in looking for information, monitoring process and comprehension, and evaluating the progress. It seems that metacognition is a key to enhance hypothesis-development performance. However, studies in ill-structured problem solving have frequently explored processes in a conceptual level and interventions, even though researchers emphasized the role of hypothesis development based on the characteristics of young and novice problem solvers. As a result of research, it is necessary to examine the effective tools for stimulating novice problem solvers' metacognition in the hypothesis-development performance, the influence of the hypothesis-development performance toward achieving a solution, and psychological factors affecting the hypothesis performance.

ASSUMPTIONS

It was assumed that all participants had completed the animal chapters, including classification, in the Korean science curriculum of elementary education. The second assumption was that the participants would have satisfactory computer skills, such as word processing, browsing, the file manipulation skills to copy, paste, and create files, and keyboarding. The third assumption was that participants would answer honestly the questions asked in a given set of questionnaires.

LIMITATIONS

This study is limited to participants who are sixth-grade students in a Korean elementary school located in urban area. Data were collected from the sixth-grade students from the fall semester of 2006. The study of results may not be generalized to all sixth graders in Korea nor to sixth graders in the United States.

PURPOSE OF THE STUDY

The purpose of this study was to examine the effect of metacognitive scaffolds in a computer-supported and problem-based learning environment on young adolescents' hypothesis-development performance. A secondary purpose was to investigate the associations between young adolescents' domain knowledge, metacognitive, and motivational factors on hypothesis-development performance in a sample of sixth-grade children.

THE EFFECT OF METACOGNITIVE SCAFFOLDS ON PROMOTING YOUNG ADOLESCENTS' HYPOTHESIS-DEVELOPMENT PERFORMANCE IN ILL-STRUCTURED PROBLEM SOLVING

INTRODUCTION

One of the cognitive activities required of problem solvers is developing viable hypotheses. Particularly, developing hypotheses or alternatives in ill-structured problem solving is thought of as a required process to build up proper solutions. The importance of hypotheses development in real-world problems has been emphasized by researchers (Abelson & Levi, 1985; Bruning et al., 2003; Davis, 1991; D'Zurilla & Nezu, 1980; Ha, 1987; Kruglanski, 1990; Nezu & D'Zurilla, 1981; Patel & Groen, 1991). Problem solving research had not clarified how the process of strengthening hypothesis development affects later problem solving performance in ill-structured problems, especially for young problem solvers, even though the process has been considered a key course of action in ill-structured domains. Therefore, motivation existed to pay special attention and investigate further the process of hypothesis development, including hypothesis generation and evaluation in ill-structured problem solving, to strengthen the performance of novice problem solvers. In addition, most of the past research has been conducted with adult problem solvers rather than young problem solvers, who have different characteristics in experience, knowledge, and cognitive development. Young problem solvers tend to have limited experience and specific knowledge related to the problem and problem-solving skills, and limited cognitive capacities compared with expert or adult problem solvers. In the present study, the focus is on the effect of hypothesis-development performance as an essential process to solve an ill-structured problem, and how metacognitive scaffolds in a computer-supported, problem-based learning environment affect the problem-solving performance of young, novice problem solvers.

Uncertainty and Ill-Structured Problems

Problems can be divided into two categories based on the presence or absence of clear paths to a solution (Sternberg, 2006): well-structured problems and ill-structured problems. In terms of clear path to a solution, there are two types of problems (Sternberg, 2006): well-structured problems and ill-structured problems. Well-structured problems are clearly presented, all the information needed to solve the problem and an algorithm that find a correct solution (Frederiksen, 1984). In the other hand, ill-structured problems often do not have easy solutions or sequential approaches and decomposition that will lead to solutions in the real-world, such as auditors' expertise (e.g., Davis, 1991), consumers' judgment (e.g., Ha, 1987), design (e.g., Simon, 1973), psychology domains (e.g., Abelson & Levi, 1985), ecological problems (e.g., Bruning et al., 2003), and medical diagnosis (e.g., Patel & Groen, 1991). These types of problems may be hard to recognize as problems, to represent clearly, to generate a solution easily, and to solve the problems according to the structuredness (Pretz, 2004).

As one of its features, problem solving of ill-structured problems tends to generate multiple solutions, or sometimes no solutions at all (Shin, Jonassen, & McGee, 2003; Kitchner, 1983). The reason can be found in the characteristics of the ill-structured problems. Ill-structured problems have vaguely defined or unclear goals and unstated constraints (Voss & Post, 1988) and no general rules or principles for describing or predicting solutions because most of the cases have no explicit means for determining appropriate action (Shin, Jonassen, & McGee, 2003). Further, they are ill-defined because of one or more of the following problem components: the initial state, goal state, or operations, are unknown or not known with any degree of confidence (Wood, 1983) in that the idea of the problem space is not as easy to work with in an ill-structured problem as it is in problems with an obviously defined given state, goal state, and operations (Mayer, 1983). The ill-structured problems that have existing vagueness in the components tend to show multiple spaces, such as a hypothesis space regarding to formulating a hypothesis about solving the problem, or a data space related to interpreting results (Smith & Kossyn, 2007).

Based on the nature of the ill-structured problem-solving processes, the key to ill-structured problem-solving can be identified as reducing uncertainty (or ambiguities), which is defined as unawareness of the outcome probabilities of a potential course of action (Adsit, 1988), or of the initial state, the goal state, the operators, and the path constraints needed to solve the ill-structured problem (Abelson & Levi, 1985; Adsit & London, 1997; Jonassen, 1997; McKenzie, 1998; Proctor & Dutta, 1995). In general, two phases in the process of solving the ill-structured problem are thought of as helping to reduce uncertainty: a problem development phase, including problem identification, problem definition, and problem representation (Abelson & Levi, 1985; Hayes, 1987), and a hypothesis development phase, including hypothesis generation and testing (McKenzie, 1998; Nowell & Simon, 1972). Through these two phases, an ill-structured problem can be transformed into a structured problem through the reduction of uncertainty (Abelson & Levi, 1985; Adsit & London, 1997).

Hypothesis Development in Ill-Structured Problem-Solving

In real-life, one often confronts problem situations that one has to solve. People tend to develop hypotheses to solve these problems in the real world. Generating and evaluating hypotheses leads the problem solver to new knowledge and beliefs by interpreting the problem circumstance based on the problem-solver's experience and knowledge. In the present study, hypothesis refers to a proposition or plausible conjecture (Misak, 2004) to explain the problem in its given context. A hypothesis gives problem solvers plausible paths to their explorations for a set of information that can guide them to find possible solutions, and hypotheses are also a product of universal and constant human activity (Wenham, 1993). For this study, there is a difference between a hypothesis in ill-structured problem solving and a scientific hypothesis. The noticeable difference with a scientific hypothesis is the collection of evidence. With a scientific hypothesis, it is necessity to have verifiability based on empirical evidence in well-defined methodological stages (e.g., experiments, mathematical calculations, or predicting and controlling phenomena) (Feibleman & Nijhoft, 1972; Frank, 1957). On the other hand, a hypothesis in ill-structured problem solving tends to pursue explanatory power that fits a solution to a problem according to available information, even though this overlaps with scientific hypotheses. If one can approach testable evidence to solve the ill-structured problem, the problem solving process will be the same as collecting evidence for a scientific hypothesis in the problem-solving context. However, in many cases of ill-structured problem-solving in real-life tasks, people tend to use a form of inference to arrive at the best explanation based on the flexible criteria, such as needs, efficiency, functioning, or satisfaction, within their problem circumstance.

Hypothesis development, including the hypothesis generation and evaluation process, can be considered as a typical strategy used in ill-structured problem solving. People form hypotheses about how a particular set of the circumstances works and use evidence gathered from experience to test and revise their hypotheses (Cronley, Posavac, Meyer, Kardes, & Kellaris, 2005). Hypothesis generation refers to the process of creating a hypothesis derived from prior knowledge and the creative process of inference related to a given information set (Lawson, 1995). In the hypothesis evaluating process, the problem solver expects to move from suggestions which are uncertain to information which is more reliable (Feibleman, 1972). Although there has been relatively little research on the evaluation of hypothesis generation compared to that on hypothesis evaluation, hypothesis generation in the real world is still considered as an important cognitive process (Adsit & London, 1997; Dougherty & Hunter, 2003).

Research (Adsit, 1988; Adsit & London, 1997; Gettys & Fisher, 1979; Gettys, Mehle, & Fisher, 1986; Quinn & Alessi, 1994) shows that when people generate a hypothesis, they usually generate one hypothesis set that is impoverished in both quantity and quality. In other words, the process of hypothesis generation that is most conspicuous is the lack of variety before justification; participants also overestimate the completeness of their hypothesis sets. There are three main factors that affect the hypothesis generation process. The first factor is the individual's cognitive capacity to produce various alternative hypotheses to a given problem. After examining individual differences in hypothesis generation, researchers (Dougherty & Hunter, 2003; Dunbar & Sussman, 1995) argue that people who have limited working memory capacity have difficulty generating more than one hypothesis. Secondly, the problem solver's motivation is a factor, particularly since their motivation to generate alternative hypotheses is assumed to be affected by needs in three separate classes (Kruglanski & Freund, 1983): (a) the need to have some knowledge on a given topic, as opposed to confusion and ambiguity, (b) the fear of invalidity, and (c) the need for specific conclusions. Third, time creates pressure on hypothesis generation (Dougherty and Hunter, 2003; Kruglanski, 1990). The research findings about hypothesis generation show that generating a larger number of hypotheses in quality and quantity allows for more predictability in problem-solving performance.

As another sub-process of hypothesis development, the hypothesis evaluation process plays a critical role in various tasks of human judgment. The evaluation process in hypothesis development evaluates problem-solvers' beliefs, which are represented by hypotheses. This evaluation is supported by the empirical evidence that experience provides (Barker, 1957). In hypothesis evaluation, the problem solver develops argumentation in two sub-processes: seeking and testing evidence. When given an ill-structured problem, a problem solver in the hypothesis generation stage attempts to provide plausible explanations to the problem. These explanations are constructed specifically to delineate a hypothesis space so further solution searching can take place. This active search for the solution happens through the hypothesis evaluation process in the hypothesis space. Hypothesis evaluation for ill-structured problems requires iterative processes along with hypothesis generation (Kassirer, 1983); the iterative process in hypothesis development is an especially practical strategy for the novice problem solver (Azevedo, Faremo, & Lajoie, 2007). Nowell and Simon (1972) stress that problem solvers can generate a correct hypothesis through the repetition process, and that the discovery of new hypotheses occurs repeatedly in a process. Schön (1983) believes both hypothesis evaluation and problem-solving are parts of a reflective conversation in which hypotheses are newly formed and problems newly framed.

Metacognitive Scaffolds

Based on the above characteristics of hypotheses in the ill-structured problem-solving process, one of the psychological factors to strengthen hypothesis-development performance is associated with problem solver's metacognition (Ge, Chen, & Davis, 2005; Ge & Land, 2004). Metacognition helps a problem solver select appropriate strategies to apply to the problem, monitor his or her own cognitive processes, activate a schema of domain knowledge, regulate iterative success and failure when the solution is applied, and control whole steps of problem solving (Kluwe & Friedrichsen, 1985; Sinnott, 1989).

Metacognition also may play an important role in improving the efficiency of problem solvers in the development of hypotheses. There are several features of poor hypothesis development which is affected by the problem solver's self-regulation. For example, problem solvers frequently show fixation effects in the hypothesis development process, such as the Eingellung effect, or mechanization of thought (Anderson, 2000; Luchins, 1942; Proctor & Dutta, 1995) where prior experience and knowledge results in a reluctance to investigate alternative procedures for a novel task, and confirmation bias, where the problem solver prefers to consider only one hypothesis and pays no attention to alternative hypotheses or other potentially relevant hypotheses (Dunbar & Fugelsang, 2005; Farris & Revlin, 1989).

Metacognitive scaffolding may help learner's metacognitive awareness in developing hypotheses in ill-structured problem solving. Hannifin, Land, and Oliver (1999) identified four scaffolds associated with a computer-based learning environment based on mechanism and functions: (a) conceptual guiding about what to consider, (b) metacognitive scaffolding providing guidance in how to think, (c) procedural scaffolding support in how to utilize resources, and (d) strategic scaffolding emphasizing alternative approaches. Particularly, metacognitive scaffolding can guide strategies toward thinking about the problem, be effective in domain specific or generic and unfamiliar contexts, and provide students with an opportunity to determine whether or not the information-gathering strategies are successful (Brush & Saye, 2001). The metacognitive scaffolding for hypothesis development supports gathering clues, monitoring, evaluating, and regulating tasks (Quintana, Shin, Norris, & Soloway, 2006).

Metacognitive scaffolds embedded in the computer-based learning environment can be used to help remedy deficiencies found in metacognitive skills, mitigated through the use of strong metacognitive scaffolds (Hannafin et al., 1999; Hill, 1995; Land &

Hannafin, 1997). Metacognitive scaffolds are tools, strategies, and guides that maintain students in a higher level of regulating their thinking. There are several types of metacognitive scaffolds, such as reflective prompts (Ge & Land, 2004; Ge et al, 2005), or mimicking expert process. In the reflective prompts, there are several features for metacognitive scaffolding. For example, they can provide hints for student's reflection and self-explanations regarding tasks, connecting metacognitive knowledge and metacognitive control, and helping students self-monitor (Ge et al., 2005).

For the present study, students participated in a computer-supported and PBL module providing metacognitive scaffolds as well as an interface designed to facilitate hypothesis development of young students. Based on the above literature review, the following two research questions guided the present study:

- Does students' use of metacognitive scaffolds affect hypothesis-development performance more than those who do not use it during ill-structured problem solving?
- Does students' hypothesis-development performance using metacognitive scaffolds impact the results of solution development more than not using it?

METHODS

Participants

Participants in the study were 172 sixth-grade students attending five classes at an elementary school in an urban school district in the Republic of Korea. For the students to be eligible to participate in the study, parental consent was obtained for 174 students. Of these 174 students, two students were absent on the day of the preliminary surveys and of the class activity, respectively. Data from the remaining 172 students was used to analyze performance. There were 78 females and 94 males, ranging in age from eleven to twelve years. The Institutional Review Board at Texas A&M University gave approval for use of human subjects for the present study.

For this study, a computer lab was used for all classes. Because the classroom had forty-two networked IBM-compatible computers with 17-inch color monitors, linked to a school internal network, students could have their own computer in the classroom.

Materials

Animal Investigator (Kim, Pedersen, & Kwon, 2006) is a web-based learning environment that includes learning modules on information seeking, classification, and problem-based learning (PBL), as well as an iterative, interactive, web-based program used to solve a real, open-ended problem in a biological and environmental context. For the present study, the PBL module of *Animal Investigator* was used independently and separated into two types for the treatment and control groups. In addition, the module in the study was modified for a more interactive interface according to the characteristics of the hypothesis development process and research design, and was recompiled into independently executable files instead of a Web based environment because of the need for coping with the unstable network condition and Web browser compatibility in each computer. The *Animal Investigator* program was developed via Macromedia Flash 8, a server-side script (PHP), and MySql.

In the PBL module, the learner is encouraged to participate in a mission as an "*Animal Investigator*." (See, Appendix B). Students read a list of news articles concerning a virtual country, Atlantis. In order to gain a better understanding of and to make a decision about a problem, students analyzed articles and reported their thoughts about what they have to know in the mission according to the virtual advisor's directions.

Problem Development Phase

After reading and finishing the analysis of the news, students described the problem statement for their mission. Students were able to go back and read the newspaper as they wrote a problem statement. In this step, learners were faced with a problem that required them to decide if a problem is identified. After submitting a problem statement, students could read a problem statement given by the virtual advisor to make equivalent conditions for the hypothesis development step. When they submitted their problem statement, the animals and the shelter information for hypothesis development were activated.

Hypothesis Development Phase

Students start to search for information using the "animal information" button in the hypothesis development stage at the *Animal Investigator* program. The student's goal for each session was to allocate a given animal to a local animal shelter according to the animal's condition and biological features. To analyze the conditions, students examined each status report and features describing each animal. Both treatment and control groups were required to generate hypotheses and investigate evidence to justify their hypothesis about solving an animal investigation problem. Only the treatment group had metacognitive scaffolds.

Solution Development Phase

To type final decisions for each animal, students clicked the solution report button at the main control panel. However, students could not run this phase before completing the previous two phases, including problem and hypothesis development. To submit their responses, students clicked on an animal shelter first, which was determined as the best shelter based on their investigations, and then wrote the rationale for their answers.

Treatment Conditions

The PBL module included the metacognitive scaffolds functions in the process of hypothesis development, particularly in the investigation steps of animals and animal shelters. When students were involved in other stages, such as problem and solution development, the scaffolds were deactivated. In this phase, the treatment group students used cognitive facilitators including three metacognitive scaffolds for the following:

Reflective Prompts for Hypothesis Development

These prompts would pop up when students stayed in the animal and animal shelter information stage for generating and evaluating the hypothesis. In the first session, these prompts popped up two minutes after clicking on the confirm button of the prompt in the hypothesis development process and repeated with the same sequence and questions for the practice of hypothesis development in the environment. In the second PBL session, these prompts popped up after four minutes at the same stage. These questions focused particularly on the hypothesis development process according to metacognition theories, regulating, monitoring, and evaluating. (1) What was the problem you were asked to solve? (2) Why do you think the current clue is important? (3) Are you repeating your investigation? (4) Do you think the current clue is helpful in solving the problem? Why? and (5) Write as much as you can about your possible solutions according to your clue.

Expert Self-Questioning Process

These questions were derived from literature that examines expert problem-solving processes and characteristics in ill-structured problem solving (Bradley, 1998; Willson, 1995), and were modified for use with early adolescents in *Animal Investigator*. Students repeatedly checked the following self-questions that emphasized repeating the hypothesis development process: (1) What is this animal's problem? (2) What do I need to know? (3) What can be a possible solution? (4) Is there an alternative solution or clue? (5) What is the best solution for this problem?

Paper-and-Pencil Self-checklist

This self-checklist played an important role in facilitating both metacognitive scaffolds in order to confirm students' responses. Students in the treatment group monitored and self-checked whenever they conducted a hypothesis development process in *Animal Investigator*: (1) I asked myself the questions in the expert question list, (2) I found a clue from the animal information, (3) I found a clue from the animal shelter's information, and (4) I answered the question of the boss in the dispatch team.

Instruments

Participants completed an assent form and two questionnaires, including one about prior domain knowledge, and a background survey. Five classes were preliminarily assigned to either one of the treatment or the control groups based on the class mean of domain of knowledge and confirmed group equivalency. The results of tests for variance differences are the follow, 1) equivalent between treatment group and control group (Levene's test: F = .813; df =1, 170; p > .05) as well as among classes (Levene's test: F = .1.33; df = 4, 167; p > .05). Teachers of each classroom administered the two instruments including the background survey and a science knowledge test at the beginning of the first class before the two main class activities.

A domain knowledge test was designed to measure students' conceptual and applicable knowledge of animal classification derived from the Korean science textbook for sixth graders. This instrument consisted of a ten-item, multiple-choice test. Items were referred from item banks developed by two regional educational service agencies and modified by the first researcher based on comments of two current teachers. Content validity was conducted for the original fifteen-item test by three sixth-grade teachers, who were involved in an urban elementary school, using the following criteria: 1) Item was appropriately selected in the light of science curriculum (agreement = 100%), (2) Item includes relevant content from the target science chapter (agreement = 100%), and (3) There are no items that are too easy or difficult to solve (agreement = 50%). In terms of the teachers' comments regarding the third criterion, five items were removed from the original domain of knowledge test because they were expected to be either too easy or too difficult, instead of having a medium difficulty level.

Finally, the groups consisted of 101 subjects in the treatment group and seventy-one subjects in the control group. In addition, the subjects' computer usage background was examined because the experimental context was a computer-based and problem-based learning module. Student's computer proficiency was required. Students reported that they had been using a computer for an average of 5.55 years (SD = 1.89) and using a computer daily for an average of 2.02 hours (SD = .088). In the perceived computer competency items, students showed no significant differences between groups in word processing ($t = -.80$, $p > .05$) and overall computer competency ($t = .00$, $p > .05$). In general, the computer usage background of the subject groups had demonstrated readiness for the present study incorporating a problem-based learning environment.

Procedures

At the beginning of the first class activity, the first researcher presented oral instructions to both groups for ten minutes to explain how to complete a session using *Animal Investigator*, including how to run the software, how to complete and copy the response form, and how to save the answer file to a shared directory in the teacher's computer. Most students were already well trained by their teachers using internal networks and relevant software to conduct the activities. Additionally, participants in the treatment groups were instructed on the use of metacognitive scaffolds, such as how to use three scaffolds: metacognitive prompts, a problem-solving process list on the computer, and a paper-based regulatory self-check. A response form used a word-processing software (HanGul), which was the standard software for word processing in the school's computer class. The reason for choosing the word processing software for completing the response form was based on the results of two pilot tests. In the pilot tests, it was found that students strongly wanted to use the word processing software instead of the paper-and-pencil form. When they used the word processing software to report their answers, they showed more satisfactory outcomes in time management and quality of their responses over the results using a paper-and-pencil form in the pilot test. The response forms, in Appendix D, were submitted on a shared folder in the teacher's computer in the school's internal network and the form was checked to make sure it was submitted correctly at the end of the session. In addition, students' responses also were stored on the database when students clicked on the each submit button for the activities.

However, in the process of copying their responses to the database file, students added to or modified their response file. Finally, three scorers scored the forms in the second class.

Most student activities in the program were directed through a virtual agent and at the activity windows. The first author administered the program to five classes for two sessions to ensure equivalent administration when using *Animal Investigator*. Each session occurred during a fifty to fifty-five minute computer class. At the request of the primary researcher, the actual class time that each session was administered was around fifty minutes instead of the regular class time, forty minutes, because the research used ten minutes before and after each class. Groups were monitored to make sure time was as equal as possible in each condition. Because the two pilot tests depended on time management and students' concentration, the final administered class time was decided to be fifty minutes.

To score students' responses, a rubric was developed through the pilot tests based on literature that measured problem-solving performance (Ge & Land, 2003; Oh, 2004; Quinn & George, 1975; Shin, Jonassen, McGee, 2003). The criteria of the rubric are shown in Appendix E. The rubric consists of descriptive criteria of two phases, hypothesis development and solution development, of problem solving that were ranked from 0 to 2. The students' responses were scored by three raters: a researcher and two teachers trained to use the scoring rubric. Each rater scored the responses individually. To assess the interrater reliability, intraclass correlation (ICC) was chosen as a statistical procedure. ICCs for the three raters were found to be .87 and .83 for the hypothesis development score and the solution development score, respectively.

Design and Data Analysis

A quasi-experimental, posttest-only design (Shadish, Cook, & Campbell, 2002) was used with the presence and absence of metacognitive scaffolds as the independent variable. The dependent variables were performances in two problem-solving phases: hypothesis development, and solution development.

For the present study, three analyses approaches were used: Multivariate analysis of variance (MANOVA), binary logistic regression for follow-up analyses, and a linear regression. MANOVA, Hotelling's T, was performed to compare the two groups: the treatment group facilitating with metacognitive scaffolds and the control group on the two dependent variables: hypothesis development (HD), and solution development (SD) to test for multivariate effects. For the follow-up analysis, a binary logistic regression was conducted to evaluate significant combinations between dependent variables because significance in multivariate analysis means there is a linear combination of the dependent variables separating the groups (Stevens, 2001). In terms of the logistic regression, the individual differences of variables were explored to understand the contribution of dependent variables. Because the univariate F conducted previously to identify the main effect ignores the relative importance of the significant variables to group differentiation in multivariate analysis (Stevens, 2001), a logistic regression was performed to determine the comparative importance of each variable to group differentiation.

RESULTS

Three sets of analyses were conducted. First, multivariate analysis of variance (MANOVA) was computed to evaluate the main effect in hypothesis-development performance by treating metacognitive scaffolds. Second, binary logistic regression analyses were conducted to determine which variables present significant effects in the model of ill-structured problem solving performance. Third, a linear regression analysis was conducted to determine whether or not the treatment is significantly influential to the final results of problem solving activities. For the present study, two statistics software and also an application were used, including SPSS 13.0 for MANOVA, a logistic regression, descriptive analyses, and assumptions, and additionally AMOS 5.0 for multivariate assumptions.

Test for Multivariate Assumptions and Data Cleaning

Before conducting multivariate analyses for the data, statistical assumptions were examined, including the assumptions of multivariate normality, homogeneity of variance, and homogeneity of variance-covariance matrices. AMOS 5.0 provides a multivariate normality coefficient, Mardia's coefficient (Mardia, 1970; Mardia, 1974). The initial coefficient was higher than the critical value of $\pm$ 2.58 at a .01 alpha level. Two univariate outliers were deleted and multivariate normality assumption was met (z = 1.30). However, hypothesis development significantly violated the assumption of homogeneity of variance across groups. To avoid potential Type II error, two dependent variables were transformed with square root transformation (Cohen, 2003). After conducting the transformation, the two assumptions were met: homogeneity of variance (HD: $p > .05$; SD: $p > .05$).

Table 1 presents the means, standard deviations, and multivariate effects for the groups' performance on two problem solving activities for ill-structured problems. The means and standard deviations of hypothesis-development performance and solution development performance in the presence and absence of metacognitive scaffolds were 3.39 (*SD* = 1.16) and 2.79 (*SD* = .86), and 2.64 (*SD* = .66) and 2.48 (*SD* = .59), respectively.

The multivariate test showed significance in a Hotelling's *T* statistic of .08, F (2, 169) = 6.70 ($p < .01$), indicating the existence of a significant multivariate effect for the treatment group when the groups are compared simultaneously on the set of two variables in that the combined dependent variables were affected significantly by the treatment (presence of metacognitive scaffolds).

Because the two groups were found to differ in the previous multivariate analysis, a post hoc procedure was conducted using a binary logistic regression to determine which dependent variables contributed to the significance in the multivariate difference analysis. The outcome of the logistic regression was the dichotomous variable (the treatment group is equal to 1 if the subjects were treated). According to the results, the hypothesis-development performance was the only significant predictor of the outcome. A logistic regression coefficient (B) was statistically significant only for HD (B = .53, $p < .01$) and the logistic regression coefficients of SD (B = .09, $p > .05$) were not statistically significant. The forward stepwise logistic regression was used to determine which pairs of groups established the model fit to the data. HD was still the only significant predictor in the model (B = .55, Wald chi-square = 11.57, odds ratio = 1.73, $p < .01$) and the insignificant Hosmer-Lemeshow test coefficient, $\chi^2(8) = 7.92$ ($p > .05$), which means the model with the HD predictor fit the data well, as described in Table 2.

Additionally, a linear regression analysis was conducted to examine the causal effect from the hypothesis-development performance to solution development performance. Two variables were correlated with each other, and the causal explanation between them can be offered for their relationship (B = .37, $t = 5.11$, $p < .01$, adjusted R-square = .13). The reason of the significant causal relationship between HD and SD might be affected by the hypothesis development activity for both groups.

Table 1

Mean Scores, Standard Deviations, and Multivariate Analysis of Variance for the Measure of Ill-structured Problem Solving Performance Measures

Group	Ill-structured problem solving performance measure							
	HD		Univariate test	SD		Univariate test	Multivariate test	adjusted R^2
	M	*SD*	*t*	*M*	*SD*	*t*	*F*	
Treatment (n = 100)	3.39	1.16	3.65 ($p < .01$)	2.64	.66	1.61 ($p > .05$)	6.70 ($p < .01$)	.07
Control (n = 70)	2.79	.86		2.48	.59			.01

Note. HD = hypothesis development, SD = solution development. a. Multivariate *F* ratio was generated from Hotelling's Trace statistic.

Table 2

Summary of Logistic Regression Analysis for the Full and Reduced Model Evaluation

Variable	B	*SE*	Wald's χ^2	*df*	*p*	Odds ratio
HD	.53	.17	9.53	1	.01	1.70
SD	.09	.27	.11	1	.75	1.09
Constant	-1.50	.72	4.28	1	.04	.22
HD	.55	.16	11.57	1	.01	1.73
Constant	-1.34	.52	6.67	1	.01	.26

Note. HD = hypothesis development, SD = solution development

DISCUSSION

In this study, the primary purpose was to investigate whether the presence of metacognitive scaffolds in the hypothesis development phase may help early adolescents' performance, as well as to examine the effects on the solution performance in ill-structured problem-solving. As per scaffolding metacognition, students were encouraged to regulate cognitive activities regarding hypotheses development sub-processes: to activate problem representations during the hypothesis development, seek information and evidence, generate multiple hypotheses, argue each hypothesis, and mimic expert problem-solving processes by using the computer-supported, problem-based learning environment.

The findings of this study led to the conclusion that hypothesis-development performance was influenced by scaffolding the young learners' metacognition in their problem solving performance on the ill-structured task. Students who worked in treatment groups performed significantly better than those who worked in control groups on developing hypotheses. Therefore, results demonstrated the effectiveness of metacognitive scaffolds and that they can be applied to the hypothesis development phase for young problem solvers. Researchers have continuously postulated the strength of developing hypotheses in ill-structured problem-solving performances (D'Zurilla & Nezu, 1980; Nezu & D'Zurilla, 1981; Buntler, Scherer, & Reiter-Palmon, 2003; Burns & Vollmeyer, 2002). Previous research regarding treating young problem solvers with metacognitive scaffolds was confirmed in the present study. The results strongly support the use of metacognitive scaffolds as aids toward better performance when developing hypotheses in ill-structured problem-solving situations.

To better understand the impact of scaffolding on metacognition, it is important to determine the extent to which the hypothesis-development performance provides a prediction of solution-development performance in ill-structured problem solving. Analyses were conducted to better understand the impact of strengthened hypotheses developed by using metacognitive scaffolds upon the resulting solution development. First, the results demonstrated that in comparisons of solution performance, both groups were not significantly different in univariate analyses. Contrary to expectations, solution development performance in the follow-up analysis produced no significant difference by scaffolding the learners' metacognition in a hypothesis-development process. There are several possible explanations for this result. First, time constraints might significantly affect solution development. Students developing their final solutions should be allowed more than enough time to analyze their hypotheses. The time constraint issue has been pointed out by researchers as a difficulty in the problem-solving research in classroom design (Dougherty and Hunter, 2003; Ge & Land, 2003; Kruglanski, 1990; Song & Grabowski, 2006). Secondly, because the instructions on each problem-solving phase did not specifically support students' efforts, some or all may have had trouble with the evaluation processes in solution development. Higher-level cognitive activities might be required for students to justify their final solution-development performance using comparison, analysis, synthesis, and argument to consider the viability of the hypotheses developed in the previous phase. However, students who are not instructed in these cognitive activities as aids to solving ill-structured problems might not demonstrate strong differences between the treatment and control groups in researching the use of metacognitive scaffolds in hypothesis development. Nevertheless, hypothesis-development performance in both the treatment and the control groups had respectively mild and small predictive power of solution-development performance, resulting in simple linear regression analysis.

Although these were mixed results on the effectiveness of the hypothesis development with metacognitive scaffolds, this study can be used for designing instructional environments in ill-structured problem solving for young problem solvers.

First, the environment with metacognitive scaffolds enables young students to increase recognition of their own hypothesis-development strategies. The metacognitive scaffolds will allow students to monitor and to evaluate themselves relative to generating alternative hypotheses, finding supportive evidence of hypothesis, and evaluating the appropriateness of hypothesis in ill-structured problem tasks. Recognizing one’s hypothesis-development processes while problem solving is an important step to making clear directions of solving the uncertain problems. In the present study, students assisted by metacognitive scaffolding showed high scores in their hypothesis performance. This was consistent with previous research regarding the importance of developing hypotheses in order to solve real-world problems (Abelson & Levi, 1985; Bruning, Schraw, Norby, & Ronning, 2003; Davis, 1991; D’Zurilla & Nezu, 1980; Ha, 1987; Nezu & D’Zurilla, 1981; Patel & Groen, 1991).

Second, to facilitate hypothesis development, instructional designs should consider young learners' developmental maturity and characteristics. The process of hypothesis development requires reflective and critical thinking, reasoning, and artumentation (Lawson, 1995). However, in developmental perspective, young adolescents just start to think of possibilities as they begin to build a system or their theories in the broad sense of the term (Inhelder & Piaget, 1958). Moreover, they begin to develop procedures of critical and reflective thinking (Lawson, 1995). Therefore, a teacher or instructional designer has to consider the level of cognitive maturity as well as cognitive competence.

Third, it is important for students to be educated thoroughly about seeking information to fit to their problem representation in a reasonable and logical manner. This study encouraged students to include evidence or information and justification from the given information for the hypothesis-evaluation process. Even though students were guided by the prompts to find clues from given information regarding animals and animals shelters, students with low scores in their response tended to guess and use their prior schema and feelings regarding the animals rather than the given information or facts. Particular students did not use the evidence thoroughly and thus exhibited weak justification performances. For example, even though the prior criterion of the problem was the animal's survival, students considered subjective criteria, such as feelings or opinions of their good friends, guessing the animal's feelings, or evaluations of the beauty of the environment.

The present study has some limitations and suggestions. First, this study uses the posttest-only, nonequivalent control group design, which is weak in validity (Shadish, Cook, & Campbell, 2001; Wiersma & Jurs, 2005) even though the similarity of the classes was identified according to the three surveys, including metacognition, prior domain knowledge, and computer competency. Therefore, the findings of the study might be limited in application to other samples. However, the results of this study may be expected to contribute to discussions on the role of hypothesis development in teaching problem-solving skills and strengthening problem-solving competency. Second, the present study was limited to a Korean sixth-grade student sample; therefore, the findings may not be able to be generalized to other populations. It is also possible that technological contexts and technology competency affects the results. Third, if students' performances could be analyzed with a qualitative point of view, there could be more insightful findings regarding the hypothesis-development performance.

Although it has been demonstrated that metacognitive scaffolds have a positive influence on the role of hypothesis development in ill-structured problem solving performance, there are several questions unanswered from the initial approaches taken regarding the details of the hypothesis process. For example, what kinds of strengthening metacognitive strategies are effective for hypothesis sub-processes, or what kinds of cognitive factors affect the students' hypothesis-development performance? With regard to these questions, future research should continue to investigate a more extensive process in ill-structured problem solving to determine if young, novice problem solvers' performances in specific phases will change as a result of scaffolding their regulation of cognitive activities during hypothesis generation and evaluation specifically. The specific components of metacognition affecting hypothesis-development performance might be considered like motivation, prior knowledge, argumentation skill, or reasoning skills. Also, it is still an open question as to whether hypothesis development might significantly affect the quality of the final solution of an ill-structured problem. However, this study provides preliminary evidence that including metacognitive scaffolds in computer-supported, problem-based learning environments can facilitate hypothesis-development performance, as well as support the prediction of the final solution performance.

THE RELATIONSHIP BETWEEN METACOGNITION AND DOMAIN KNOWLEDGE ON YOUNG ADOLESCENTS' HYPOTHESIS-DEVELOPMENT PERFORMANCE IN ILL-STRUCTURED PROBLEM SOLVING

INTRODUCTION

One of the major goals of education is the development of students' problem solving skills for academic challenges and the transfer of these skills to new academic tasks or problems. Problem solving is one of the most meaningful and important kinds of cognitive functioning (Jonassen, 1997). Problems to be solved are of various types and characteristics: many researchers agree that problems differ as to how much structure they provide the problem solver (Hayes, 1987; Jonassen, 1997), and how many, how clearly, and how reliably the constituent components are represented in the problem (Jonassen, 2004).

The types of problems can be discussed according to the presence or absence of clear paths to a solution (Sternberg, 2006), or the type of problem structure: well-structured problems and ill-structured problems. Particularly, ill-structured problems may be hard to even identify as problems, to represent clearly, to generate a solution easily, and to ultimately solve the problems in terms of the structuredness (Pretz, 2004). In general, ill-structured problems are characterized as having multiple solutions, solution paths, or sometimes no solutions at all, having vaguely defined or unclear goals and unstated constraints, or having no general rules or principles for describing or predicting solutions (Kitchner, 1983; Shin, Jonassen, & McGee, 2003; Voss & Post, 1988; Wood, 1983). Because most of these cases have no explicit means for determining appropriate action, they are ill-defined.

In the study, three stages of the ill-structured problem-solving process were considered based on previous literature, instead of four or five stages (Ge & Land, 2003; Jonassen, 1997) because the following problem-solving stages may not be clear for young adolescent problem solvers: problem identification, hypothesis development with hypotheses generation and evaluation, and solution development with solution generation and evaluation.

Problems in the real world are sometimes called ill-structured problems or ill-defined problems because there are unclear paths to a solution (Sternberg, 2006). With regard to ill-structured problem-solving process, hypothesis development is central to solving problems in order to decrease uncertainty in real-world problems (Abelson & Levi, 1985; Adsit & London, 1997; Ge & Land, 2004; McKenzie, 1998; Nowell & Simon, 1972). Hypothesis development in ill-structured problem solving refers to developing a proposition or plausible conjecture that can be viewed as being close to a solution (Kruglanski, 1989; Misak, 2004). The development of hypotheses is significant in the process of solving problems, acquiring new knowledge from the surrounding world, scientific discovery, and general epistemic processes (Bourne, Dominowski & Loftus, 1979; Bruner, 1951, 1973; Kruglanski, 1989; Newell & Simon, 1972; Popper, 1972).

Development of hypotheses has been considered as an essential approach when people do not have knowledge and experience about the problem and phenomena (Alexander, 1992). Research regarding hypothesis development is more focused on adult subject groups than on child and adolescent groups, as well as being more focused on the individual psychological and instructional factors than the integrated theoretical model. Therefore it is necessary to develop a theoretical model to explain internal characteristics of a novice problem solver with regard to hypothesis-development performance in ill-structured problem solving.

Contained in the literature on hypothesis development, there are problem solvers' cognitive and motivational characteristics regarding the hypothesis development (Alexander, 1992; Klahr, Fay & Dunbar, 1993; Kruglanski, 1989, 1990; Norman & Schumidt, 1992), for example, information seeking, multiple hypothesis generation, iterative performance, differences between novices and experts, and frequently checking problem representation (Azebedo, Faremo, & Lajoie, 2007; Kaisser, 1983). Research suggests that three factors—motivation, metacognition, and prior domain knowledge—may affect hypothesis development. In the present study, a causal model examined the novice problem solver's cognitive and motivational factors on hypothesis-development performance in ill-structured problem solving using structural equation modeling. The subsequent review will present bases for hypothesizing relationships in the model.

Impact of Domain Knowledge on Hypothesis Development

The influence of domain knowledge in problem solving, reading comprehension, memory, and other cognitive activities has been emphasized by researchers (Alexander, 1992; Alexander, Johnson & Schreiber, 2002; Bjorklund, 2000; Schauble, 1990, Bruner, 1973). Domain knowledge is defined as "the realm of knowledge that individuals have about a particular field of study (Alexander & Judy, 1988)," which may be named in many different ways, such as subject-matter knowledge, domain-specific knowledge, and content-specific knowledge (Alexander, 1992). When problem solvers change their knowledge regarding the problem or apply new knowledge to the problem (Barrows, 1985), prior domain knowledge needs to be activated to facilitate their understanding and the construction of new knowledge (Albanese & Mitchell, 1993; Norman & Schumidt, 1992). When students do not activate their prior domain knowledge, they might have difficulties in processing new information to solve the problem. According to Alexander et al. (2002), when children possess large amounts of knowledge about a domain, they process information from that domain very quickly.

It has been shown that domain knowledge can influence the hypothesis development process to help build or develop plausible hypotheses and to interpret and evaluate evidence (Alexander, 1992; Klahr, Fay, & Dunbar, 1993). According to Shapiro (2004), domain knowledge is a fundamental source of information when a given topic is completely unfamiliar. As well, domain knowledge facilitates both practice in applying strategies within the domain and the ability to extract essential information from sources which might appear irrelevant to a given problem.

The hypothesis development processes are more often used by novice problem solvers than by expert problem solvers because the novices are trying to compensate for their poor domain knowledge and lack of experience at developing solutions (Alexander, 1992). To overcome the lack of knowledge, novice problem solvers need to develop skills in acquisition, retention, and apply acquired relevant domain knowledge gained to a variety of problem situations (Norman & Schumidt, 1992; Tan, 2007). Alexander (1992) emphasized that building domain knowledge structure is equivalent to development of expertise in the domain. There exists a recognition of difference in the meaning of domain knowledge between an expert and a novice problem solver.

The primary requirement for solving ill-structured problems in expert-level research and academic learning is important as well as sufficient declarative and domain-specific knowledge (Arts, Gijselaers, & Segers, 2006). Unlike the adult problem solver, a young problem solver's performance is more influenced by familiarity with the given task than by the degree of prior domain knowledge (Alexander et al., 2002).

Metacognition in the Hypothesis Development Process

Along with the problem solver's prior knowledge base, one could consider the role of metacognition in developing hypotheses. Metacognition refers to the intentional control of cognitive activity (Brown, 1980; Flavell, 1985), often called "cognition about cognition" or "thinking about thinking." Recently, metacognition has been given a central role among learners' diverse activities, such as problem solving (Kruglanski, 1989), critical thinking (Jones & Ratcliff, 1993), or social cognition (Flavell, 1985). Particularly, metacognition plays an important role in reasoning during problem solving because metacognition can help the processes in terms of planning how to approach the many and varied ways of solving a problem, as well as evaluating one's performance (Davidson, Deuser, & Sternber, 1996). In the problem-solving literature, it is not difficult to find research that compares the problem-solving characteristics between expert and novice problem solvers, such as the metacognitive processes observed in expert problem solvers. Expert problem solvers tend to spend their time analyzing problems qualitatively, as well as having effective and continuous self-monitoring regarding their comprehension and processing strategies (Hoover & Feldhusen, 1994; Willson, 1995). To monitor, regulate, and evaluate one's thinking are metacognitive strategies known to play a critical role in strengthening reflective reasoning and problem solving. As a higher-order cognitive process (Lezak, 1995), hypothesis development is central to establishing a reasonable solution for the given problem context, mainly in real-world professional domains like establishing medical diagnoses, auditing problems, and engineering design problems.

The role of metacognition in hypothesis development can be viewed as two sub-processes in the ill-structured problem-solving process: hypothesis generation and hypothesis evaluation. Hypothesis generation is the process of creating alternative possible explanations for a given information set (Adsit & London, 1997). The problem solver forces structure onto the ill-structuredness by eliciting information, ordering investigations, and generating hypotheses (Simon, 1973). People form hypotheses about how the world works and use the evidence gathered from experience to test and revise their hypotheses (Cronley et al., 2005). When given an ill-structured problem, hypothesis generation attempts to provide plausible explanations. These explanations are constructed specifically to delineate a problem space so further search for the solution can take place; this active search for the solution is hypothesis evaluation. Although hypothesis generation and testing are separately mentioned, both processes are thought of as an interactive process used to get the best explanation for a problem. Adsit and London (1997) discussed the relationships between hypothesis generation and evaluation: problem solvers who generated the correct hypothesis before beginning the testing were more likely to solve the problem. Additionally, unproductive hypothesis generation may cause hypothesis evaluating inadequacies and might be a barrier to proficient hypothesis-evaluating performance (Adsit & London, 1997).

Even though researchers (Adsit & London, 1997; Klahr & Dunbar, 1988) emphasize the importance of generating hypotheses in the problem-solving process, they do not provide enough argumentation concerning the strategies necessary to strengthen the process. Several researchers in social psychology point out the role of metacognition in the hypothesis generation process (Kruglanski, 1989, 1990). Solving ill-structured problems requires applying strategies such as collecting information from possible sources as well as investigating various competing hypotheses to decrease uncertainty (Adsit & London, 1997; Weimer, 1979). However, problem solvers, particularly novice problem solvers, tend to be weak in generating various competing hypothesis sets, evidenced by the inferior quality and insufficient quantity of hypotheses (Adsit & London, 1997; Fisher et al., 1983).

In the hypothesis evaluation process, two phases, validating the hypothesis and collecting evidence, can be influenced by the metacognitive skills and competence of problem solvers. Problem-solving processes in ill-structured problems include the process of validating the hypothesis and the solution. Validating the hypothesis requires more extensive information-processing activity (Petty, Briñol & Tormala, 2002) because problem solvers in uncertain contexts need to make an effort to look at other ideas by iterative and comparative processes, using alternative hypotheses to decrease errors and to determine the correctness in validating their approach (Adsit & London, 1997). In validating a hypothesis in uncertain situations, the problem solver's cognitive abilities, such as confidence and argumentation, can affect the quality of the hypothesis. Most importantly, metacognitive ability can influence the quality of confidence and argument about one's own beliefs (Petty, Briñol & Tormala, 2002). In addition, metacognition can control a problem solver's iterative information-gathering process through the course of collecting evidence for validating a given hypothesis. For example, problem solvers in professional domains need to continue the hypothesis development process until they gather adequate evidence to solve the problem at hand (Jones, Jensen, & Edward, 2000). In the process, the domain expert may have sufficient knowledge and ability to regulate the following issues: where and how to find evidence effectively, which source is more valuable for their situation, and whether or not they need to find more evidence. The interaction between such knowledge and metacognitive skills is essential for effective problem solving (Higgs, 1997; Jones et al., 2000).

With regard to the role of metacognition in hypothesis development, researchers have continuously yielded results that problem solvers need to regulate their cognitive features in generating working hypotheses, disconfirming some approaches or reinterpreting to available information, and evaluating alternative hypotheses (Klahr, Fay, & Dunbar, 1993; Klayman & Ha, 1987; Sullivan, 1991).

Motivational Aspects and Metacognition

Regarding hypothesis development, researchers postulate that people's performance in generating and validating hypotheses depends on their motivation (Kruglanski, 1989). The role of motivation to solve problems has been researched and investigated in educational fields. Motivation has been emphasized as an inevitable factor of human problem solving, human judgment, and reasoning (Kruglanski, 1989; Kunda, 1990). In general, a student's motivational aspects, including self-efficacy, interests, intrinsic motivation, valuing of academic tasks, perceptions of belonging, and outcome expectations, (Walker, Greene, & Mansell, 2006; Zimmerman & Schunk, 2008) are often suggested as positively impacting students' academic performance as well as problem solving performance. In the view of motivation based on a problem solver's interest, people who have an interest in problem solving will be more successful than those without an interest in solving the problem (Mayer, 1998). With regard to the relationship between motivation and hypothesis development, Kruglanski (1990) proposed that people tend to generate multiple hypotheses on a topic and search for information relevant to those hypotheses because of being motivated.

Motivation is a key to successful performance beyond academic work for a problem solver. Particularly, intrinsic motivation is recognized by many researchers as a stronger predictor than extrinsic motivation or a student's perceptions in achievement domains (Rawsthorne & Elliot, 1999), and in problem solving in academic or realistic settings (Mayer, 1998; Weiner, 1986; Kruglanski, 1998, 1990). Intrinsic motivation concerns performing activities for their own sake, which is associated with enjoyment from the learning process itself, curiosity, the challenge of learning tasks, persistence, a high degree of task involvement, interest, and inherent satisfaction in a task or activity (Berlyne, 1965; Deci, 1975; Deci & Ryan, 2000; Gottfried, Fleming, & Gottfried, 1998; Hmelo-Silver, 2004; Zimmerman & Schunk, 2008). According to Cordova and Lepper (1996), when students are strongly intrinsically motivated in terms of the results prom properly using the strategies in the learning environment, students were able to engage more deeply in the activities, to challenge themselves using more complex operations, and to learn more from the activities, as well as to show higher subsequent levels of aspiration and feelings of perceived competence. Motivational beliefs relating to interest, enjoyment, or sense of satisfaction about a specific subject domain can be considered when investigating students' intrinsic motivation across academic contexts as predictive of hypothesis performance on subject activities.

This paper concerns the association between motivation and metacognition when young adolescents develop hypotheses. There is growing evidence that individual interests are positively related to metacognitive strategies including elaboration, seeking information when confronted with a problem, and engagement in critical thinking. An interesting view about the relationship between metacognition and motivation is that people's motivational states are products of a phase of metacognitive processes (Winne & Hadwin, 2008; Wolters, 1998; Zimmerman & Schunk, 2008). These researchers asserted that regulating motivational states is similar to other process of regulating aspects of students' cognitive activities. Winn and Hadwin (2008) noted that students regulate their activities based on their motivation in three different categories: change conditions, change operations, and change standards. These changes are the results of students' satisfaction based on their own criteria. When students regulate their processes, they temporally engage in direct ways with their work, and monitor the products created based on what they perceive a task to be. Students monitor products along with goals and plans. The products can include a perception of effort that increases with their satisfaction after finding an answer to a problem. Finally, they can evaluate alternatives they themselves generate about how to change conditions, operations, or standards for a task to make it more satisfying. After completing four phases, students can move into the next task and change their previous approach by regulating their motivational state.

Purpose of the Study

This study examined the associations between young adolescents' domain knowledge, metacognition, and motivation on hypothesis-development performance in a sample of sixth-grade children. Although the literature discussed earlier presented individual influential factors to hypothesis development, insufficient research and discussion exists regarding the effects of domain knowledge and psychological factors on hypothesis development in children. Studied closely in an effort to gain an understanding of the relationship between hypothesis-development performance and psychological factors, was a hypothesized model that examines the relationship between metacognition, motivation, domain knowledge, and hypothesis performance in a computer-based and problem-based learning environment, as shown in Figure 1. Three dependent variables were measured, including two latent variables, one manifest variable, and one independent variable. In the model, a total of eight observed variables were employed. Our primary hypothesis was that all factors would affect the outcome measure, hypothesis-development performance. In terms of more specific hypotheses, we estimated that metacognition would have greater influence on the hypothesis outcome than the other variables. We also expected that motivation variables would be associated with hypothesis-development performance and also exert positive influence, as well as being influenced by metacognition. We expected that prior knowledge of students would be related to the hypothesis-development performance as well as two latent variables, metacognition, and motivation.

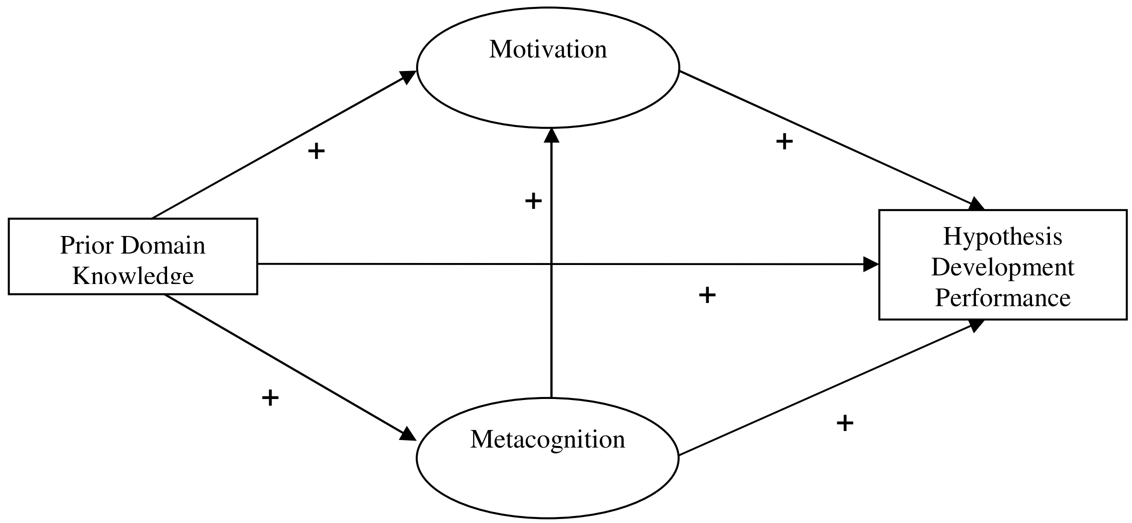

Figure 1. Presents the hypothesized model establishing the hypothesized relationships between research variables.

METHODS

Participants

Participants in this study were 101 sixth-grade students at an elementary school in an urban school district in the Republic of Korea, ranging in age from eleven to twelve years. The sample included forty-six (45.5%) females and fifty-five (54.5%) males.

Materials

To create a hypothesis development circumstance using ill-structured problem solving, a web-based problem solving environment, *Animal Investigator* (Kim, Pedersen, & Kwon, 2006), was employed. Animal Investigator includes three modules on information seeking, classification, and problem-based learning (PBL) in a science and environmental-learning context.

For the present study, the PBL module was separated into an independent executable file to guarantee the stable PBL environment for the student. In the module, the student is encouraged to solve problems as an "Animal Investigator." The PBL module was designed based on the following problem-solving processes for resolving ill-structured problems: problem identification, hypothesis development, and solution development. In problem identification, the electronic newsroom presents articles concerning a virtual country, Atlantis, and the problem solver's own country, focusing particularly on an oil spill accident and the dispatching of animal experts to rescue animals harmed by the oil spill (see, Appendix C). After reading the news articles, students are required to identify a problem, and if a problem is identified, type and submit their problem statement. After submitting their problem statement, students can read a problem statement provided by a virtual advisor to help isolate the hypothesis-development stage from the problem-identification stage. In the second stage, students develop their possible solutions based on specific pieces of information collected from general information about the animal and different animal shelters. In this phase, students develop hypotheses which they then use to allocate a given animal to a local animal shelter according to the animal's health condition, biological features, and environmental preferences. Students develop hypotheses with guide support from the interactive system. In this stage, students are supported in developing their hypotheses by system tools that support their metacognitive processes: metacognitive prompts, and interactive guidance using an expert self-questioning process. In the final phase, solution development, students type and submit their final decision regarding which local animal shelter they selected as well as evaluation statements for allocating a given animal to an animal shelter that could provide the best conditions for the animal.

Animal Investigator was developed using Macromedia Flash 8, a server-side script (PHP), and MySql. The PBL module was modified from the original version to create a more interactive interface based on the characteristics of problem solvers who will be developing hypotheses, such as an easy user-interface for iterative performance that will also be interactive with contents and tools I such as metacognitive prompts) for problem solvers.

Instruments

To collect the data for the study, the researcher conducted assessments using four questionnaires to determine domain knowledge, metacognition, motivation, and hypothesis-development performance. Instruments included the following: a domain knowledge test, the Junior Metacognitive Awareness Inventory (Jr. MAI, Sperling, Howard, Miller, & Murphy, 2002), a motivation assessment, Motivated Strategies for Learning Questionnaire (MSLQ, Pintrich & De Groot, 1990); and a hypothesis development form. All instruments were administered in the Korean language. The Jr. MAI and MSLQ were translated by the author of this paper. To ensure the adequacy of translation, the two questionnaires were then independently back-translated by two independent translators into the English language. The two translators are both doctoral students, one with experience working as an expert translator and the other with experience working as an elementary school teacher in Korea. The original surveys and back-translated versions were compared. The back-translation process is known as a contribution to the reliability and validity of research (Brislin, 1970). Items judged to have slightly different meanings had the item's wording changed to remedy the differences.

Measures of Domain Knowledge

Students' prior domain knowledge was assessed with a science knowledge test including conceptual knowledge and application regarding animal classification. The test is a ten-item, multiple-choice test based on the Korean science textbook for sixth graders. Items were referred from item banks developed by two regional educational service agencies and modified by the first author based on the comments of two current elementary teachers. Content validity, which is important for achievement or cognitive-ability tests (Gay & Airasian, 2000), was confirmed by four sixth-grade teachers who, in the previous semester, examined the original fifteen-item test with the following criteria: (1) Item was appropriately selected in the light of science curriculum (100%), (2) Item includes relevant content from the target science chapter (100%), and (3) There are no items that are too easy or difficult to solve (50%). According to the comments regarding the third criteria, five items were removed from the domain of knowledge test because those questions were evaluated as too easy for sixth-grade students even though the difficulty had been expected to reach as medium level. Finally, a ten-item test was employed to measure students' domain knowledge.

Measures of Metacognition

The Junior Metacognitive Awareness Inventory (Jr. MAI) (Sperling et al., 2002) for sixth to ninth graders was used in the present study to measure metacognition by measuring the participants' knowledge of cognition, as well as to measure regulation of cognition. The Jr. MAI is an eighteen-item self-report questionnaire about the way students learn, and is intended for use in grades six through nine. The Jr. MAI provided a reliable measure of metacognition for young adolescents as well as measuring an overall metacognition construct (Sperling et al., 2002). Sperling et al. (2002) reports that the Cronbach alpha reliability coefficient of the Jr. MAI is .85. Respondents are asked to report their estimation on a 5-point Likert scale (1 = never to 5 = always) of the frequency with which they engage in cognitive behaviors when learning and studying. Students rate items such as 1) "*I know when I understand something*," 2) "*I know what the teacher expects me to learn*," and 3) "*I use my learning strengths to make up for my weaknesses*". In this study, the score reliability of Jr. MAI demonstrated a good value with Cronbach alpha coefficient, $\alpha = .82$.

Measures of Motivation

To measure student's motivation, the Motivated Strategies for Learning Questionnaire (MSLQ, Pintrich & De Groot, 1990) was employed. The MSLQ, a self-report instrument designed to measure junior-high school students' motivation and self-regulated learning in specific classroom contexts, was adapted as the instrument to measure students' motivation as explored in this study. The MSLQ has been used widely in investigating students' motivation (e.g., Chen, 2002; Duncan, & McKeachie, 2005) and for exploring the multidimensional construct of motivation in students' learning (Paulsen & Feldman, 1999).

The MSLQ was developed to measure both expectancy for success and judgments of a given student's ability to accomplish an academic task (Duncan, & McKeachie, 2005). The instrument consists of sub-scales for self-efficacy, intrinsic value, test anxiety, cognitive strategy use, and self-regulation. The MSLQ consists of two structures, a motivation section and a learning strategies section. The construct of motivation was specifically defined in terms of the three subscales of intrinsic motivation, self-efficacy, and test anxiety. For this study, items related to all three motivational factors have been extracted from the original form (Pintrich & De Groot, 1990). For the motivation factor in the study, we employed three items from a single subscale, intrinsic value: 1) "*It is important for me to learn what is being taught in this class*," 2) "*Even when I do poorly on a test I try to learn from my mistakes,*" and 3) " *Understanding this subject is important to me.*" Students responded to each item on a seven point scale (1 = not at all true of me to 7 = very true of me) regarding their motivation in class. The original MSLQ (Pintrich & De Groot, 1990) showed adequate internal consistency and predictive validity; scores on the subscales of the motivation scale were related to classroom academic performance. For the present study, score reliability demonstrated a good value with Cronbach alpha coefficient, $\alpha = .76$.

Measure of Hypothesis Development

Students were expected to generate hypotheses and investigate clues to justify their hypotheses about solving the ill-structured problem. In the hypothesis development form, a model of a well-developed example was provided as well as the form, which was guided with 'if…. then' framed statements. In order to facilitate the process of hypothesis generation and evaluation for young adolescents who have an insufficient level of abstract thinking and reasoning regarding hypothesis development, students were guided in the form of 'if … then' statements, for instance: If the animal (animal's conditions) can go into the animal shelter (animal shelter's conditions), then the animal may stay well because ( ).' Appendix C. The statement includes multiple clues (i.e., evidence) from the given animal's description and the shelter information in *Animal Investigator*.

To evaluate students' outputs, a rubric system was developed based on literature that assesses hypothesis-development performance in ill-structured problems (Shin, Jonassen, McGee, 2003; Oh, 2004; Ge & Land, 2003; Quinn & George, 1975). The students' responses were scored by three raters: a researcher and two elementary school teachers trained to use the scoring rubric. Raters scored each student's response files individually. The interrater reliability was calculated using intra-class correlation (ICC). ICCs for the three raters were found to be .86 for the hypothesis development score.

Procedures

For the students to be eligible to participate in the present study, informed-consent forms and descriptions of the study for parents were distributed in classrooms by the teachers for the students to take home. The informed-consent was obtained for one hundred two students. From the one hundred two students, one student was absent on the day of completing the surveys.

There were three steps in the present study. In the first step, three questionnaires were administered by class teachers. In the second step, oral instruction was presented by the researcher to the students on how to use *Animal Investigator,* how to write their hypotheses in the response form, and how to save the response file to a shared directory in the teacher's computer. Then, students attended the in-class activities to complete the hypothesis-development performance in *Animal Investigator*. After analyzing the problem and relevant information, students started to search for clues from the information provided about the animal and the animal shelters in the hypothesis-development stage for a rescued animal. Students generated hypotheses and investigated clues to justify their hypotheses about solving a given problem. Students filled out a response form using word-processing software (HanGul), which is the standard software for word processing in the school's computer class, and then students submitted their work by copying the form into a shared folder in the teacher's computer on the school's internal network. Each response form was checked by the first author to make sure an actual response file was submitted at the end of the session because some students were trying to submit a linked file instead of their working file. In the third procedure, students conducted their problem-solving activities with a different animal; there was no oral instruction. For this latter procedure, student activities in *Animal Investigator* were directed through a virtual agent and at the activity windows. The first author, along with a computer-class assistant teacher, administered the protocol to three classes for two sessions to ensure equivalent administration when using *Animal Investigator*. Students attended two sessions to solve problems for two animals respectively for around fifty minutes respectively, instead of the regular class time of forty minutes. To accomplish the hypothesis-development task, students conducted the given activities for thirty minutes. Every group was monitored to make sure the time consumed was as equal as possible in conducting the hypothesis development. For the final evaluation, the results from the second session were also evaluated by the three raters.

Data Analysis

We specified a hypothetical model with variables for relationships among metacognition, prior domain knowledge, motivation, and hypothesis-development performance. According to the literature review, metacognition, prior domain knowledge, and intrinsic motivation are hypothesized to be predictors of hypothesis-development performance. Paths from prior knowledge to metacognition and motivation also were added to the model. In addition, construct reliability was calculated for each specific construct's reliability using the formula developed by Hancock (Hancock, 2001; Hancock & Mueller, 2001).

Structural equation modeling (SEM) was used to estimate parameters and hypotheses of the hypothesized model using AMOS 5 (Arbuckle, 2003). SEM is a multivariate analysis method used to estimate a theoretical model including multiple hypotheses and causal processes, which combines several statistical methods such as confirmatory factor analysis, multiple regression, and path analysis (Bentler, 1988; Byrne, 1998; Kline, 2004). The SEM technique was chosen for the present study because it allows 1) estimation of the influence of measurement errors affecting the estimated model, 2) describing the latent structure with underlying measured variables in an effective and convenient way (Byrne, 1998; Kline, 2004; Raykov & Marcoulides, 2000; Ullman, 1996), and 3) developing a theoretical model based on accepted theory (Kline, 2004). The maximum-likelihood estimation method on covariance matrices was also used in the present analyses.

We used a variety of model-fit indices to evaluate the overall fit of the observed data to the hypothesized model because of a more comprehensive evaluation of model adequacy (Brown & Cudeck, 1993; Hu & Bentler, 1999; Kline, 2004). For model evaluation, five statistics are reported to evaluate the model fit to the data: chi-square(χ^2), χ^2 / degree of freedom (*df*), the comparative fit index (CFI, Bentler, 1990), Bentler-Bonett normed fit index (NFI, Bentler & Bonett, 1980), and the root-mean-square error of approximation (RMSEA, Browne & Cudeck, 1993).

The goodness of fit statistic has the following cutoff: a non-significant chi-square (χ2) means there is a good model fit. However, because chi-square is especially sensitive to the sample size and it is possible to mislead model adequacy (Chou & Bentler, 1995), we also reported χ^2/df . An acceptable value of χ^2/df is a ratio of less than 2 (Byrne, 1989; Marsh & Hocevar, 1985). A CFI and NFI value over .90 indicates an acceptable fit and over .95 is preferable for consideration as evidence of a good fit of the model to the data (Hu & Bentler, 1995, 1999). RMSEA values range from 0 to 1, with values less than .05 accepted as a good fit of the model to data and a value of about .08 or less for the RMSEA being a reasonable error of approximation. A value greater than .01 is not recommends against employing the model (Brown & Cudeck, 1993).

In accordance with the two-step approaches of Anderson and Gerbing (1988), the first step of the analysis was testing the factor structure in the hypothesized model; confirmatory factor analysis was conducted to evaluate that the constructs sufficiently predict manifest variables in the model. The measurement model specifies the relation of the observed indicators to their underlying constructs with the constructs allowed to intercorrelate freely (Anderson & Gerbing, 1988) and estimated covariance with bidirectional paths between latent variables (Hatcher, 1994). The second step in the analysis tested a structural model with directional paths and the hypothesized mediating pathway. According to the results, the model was revised to improve the model fit to the data based on model fit indices.

RESULTS

Table 3 presents the means, standard deviations, and Pearson's correlation coefficients for all eight measured variables included in the present study. Between-subjects effects of gender on all variables were examined to determine if they might affect the main analysis using MANOVA (8 variables × gender). None of the main effects were significant (Fs= 1.31, $p > .05$), indicating that between females (n = 46) and males (n = 55), gender had no effect on any of the variables.

Before empirically testing the theoretical model in the present study, the multivariate normality across measured variables was examined before conducting the maximum likelihood procedure in AMOS (Arbuckle, 2003). The result of Mardia's coefficient of multivariate kurtosis (Mardia, 1970), -1.84 (Critical ratio = -.73), indicated that the data met the requirements for multivariate normality assumption. From the dataset, six missing values were found. Missing data from instruments was handled via multiple data imputation because, in multivariate settings, multiple imputation is more considerable than list-wise deletion (Kline, 2004). In this study, missing values were replaced by estimated values using Norm 2.03. Finally, six responses were replaced by the estimated values from the imputation.

The measurement model was assessed first. Confirmatory factor analysis (CFA) was used to examine a measurement model with an acceptable fit to the data. Two latent variables were used in the structural equation model testing: metacognition and motivation. The calculated construct reliabilities of the latent variables, metacognition (.67) and motivation (.66), reflected acceptable construct reliabilities (Hancock, 2001).

Table 3

Intercorrelations Among Proposed Indicators

Indicators	*M*	*SD*	1	2	3	4	5	6	7	8	Factor loading
Metacognition											
1. META1	3.45	.98									.66
2. META2	2.88	1.05	.43**								.64
3. META3	3.05	1.10	.50**	.48**							.76
Academic Motivation											
4. Motiv1	5.61	1.36	.12	.14	.24*						.69
5. Motiv2	4.92	1.45	.02	-.03	.16	.29**					.46
6. Motiv3	5.46	1.28	-.05	-.11	.02	.56**	.38**				.81
7. Domain Knowledge	8.55	1.14	.20*	.23*	.21*	.09	.12	.05			
8. Hypothesis Development	13.00	7.56	.21*	.35**	.34**	.24*	.12	.07	.38**		

Note. *M* = mean, SD = standard deviation. *N* = 101. Meta1= understanding, Meta2 = knowing expectations, Meta3 = Using learning strategies, Motiv1= Importance of learning, Motiv2 = Reflecting mistakes, and Motiv3 = Importance of subject

* $p < .05$. ** $p < .01$.

The values of the model fits indicated a good fit to the data: χ^2 (8, N = 101) = 14.12; CFI = .95; NFI = .89; RMSEA = .09 (90% lower confidence limit = .00, and upper confidence limit = .16). All the loadings of measured variables were significant in that all of the respective latent variables were adequately measured by their indicators in Table 2. The range of standardized factor loadings on the latent variables was .46 to .81. Therefore, the structural model was tested with the measurement model as second step of SEM.

The second step in the analysis tested a structural model with directional paths and the hypothesized mediating pathway. As illustrated in Figure 1, the hypothesized structural model included two latent variables with three indicators, respectively, metacognition and motivation and the two manifest variables of prior domain knowledge and hypothesis-development performance. In the analysis, all latent constructs and each of the single indicators were correlated amongst each other to examine associations among the latent variables and measured variables.

The structural model results revealed that the hypothesized model (Figure 1) fit the sample data well: χ^2 (16, N = 101) = 18.70, p > .05, CFI = .98, NFI = .89, and RMSEA = .04 (90% lower confidence limit = .00, and upper confidence limit = .10). The χ^2 / df ratio was 1.17, which is adequate based on Kline's recommendation (2004) of less than 3 being considered adequate. The CFI and NFI surpassed the cutoff value .90 and the RMSEA produced a good fit value compared to the criterion of .5 in the hypothesized model. In addition, the χ^2 / df value was a satisfactory fit as follows: the initial model was revised by dropping the motivation factor in the model because none of the paths showed significant regression coefficients with prior domain knowledge, metacognition, or hypothesis-development performance. In the final model, the results revealed the model that presented a good fit to the data: χ^2 (4, N = 101) = 2.42, $p > .05$, CFI = 1.00, NFI = .98, and RMSEA = .00 (90% lower confidence limit = .00, and upper confidence limit = .12). The χ^2 / df ratio was an adequate value, .61.

The final model is presented in Figure 2, which presents the significant standardized regression weights. According to the results, the final model allowed us to understand whether prior knowledge and metacognition can predict hypothesis performance. Figure 2 presents conclusions that the prior domain knowledge of young adolescents is related to hypothesis-development performance, (β = .27, p < .01) as well as metacognition being related to hypothesis-development performance (β = .36, p < .01). As predicted, there is a significant path from prior domain knowledge to metacognition (β =.31, p < .01).

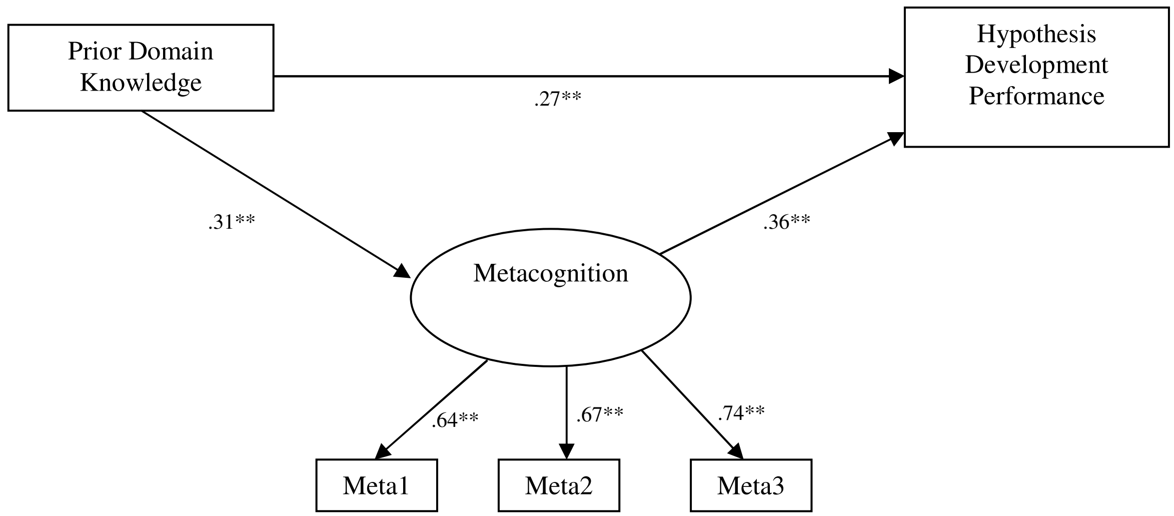

Figure 2. Final structural model of hypothesis-development performance. All estimated parameters are standardized. The large circles presents the latent variable, metacognition; the large rectangles represent measured variables. Residuals were also estimated, but not included in the figure. Model fit: χ^2 (4, N = 101) = 2.42, p > .05, CFI = 1.00, NFI = .98, and RMSEA = .00, and χ^2 / df ratio =.61.

** $p < .01$.

DISCUSSION

Most existing theories and research on ill-structured problem solving in the educational field focus on externally manipulating problem identification and solution development. However, researchers rarely attempt to examine how the associations among the factors are related in a model, nor do researchers explain why an investigation of the role of factors is important to strengthen hypothesis development and to design more effective instructional environments for students in K-12. The present research is motivated by the need to empirically examine psychological factors that impinge on the process of developing hypotheses to reach the most reasonable solution in ill-structured problem solving scenarios. The present model provides evidence of how young adolescents' prior knowledge and metacognition affect hypothesis-development performance. In terms of this model, the cognitive factor(s) that are dominant in the hypothesis development model could be determined. Also, the model could be explained based on the findings of expert and novice problem solving strategies in real-world contexts.

The goal of the present study was to investigate whether three predictors - prior knowledge, metacognition, and motivation - play roles in predicting young adolescents' hypothesis-development performance as conducted in a computer- and problem-based learning environment in a sixth-grade sample. The study results indicated that prior knowledge and metacognition did indeed predict hypothesis-development performance. Contrary to expectation, in this study the student's motivation did not play a significant role as a predictor. Perhaps the lack of effect is due to the different motivational belief systems related to academic tasks versus related to hypothesis-development tasks.

Motivation on the hypothesis development task, such as self-efficacy, may be more influential than the type of motivation that is measured in a school context. Regarding the influence of self-efficacy on hypothesis development, Kruglanski (1990) revealed that generating causal hypotheses depends on a person's motivation as well as one's ability to generate such hypotheses. An individual problem solver's self-efficacy, as a component of motivation on the activity, might have some possible positive impact on a young adolescent's performance in developing hypotheses.

The current findings support the idea that domain knowledge is closely related to hypothesis-development performance by older children in ill-structural problem solving. It seems that older children with higher levels of content knowledge may have possessed higher levels of performance in hypothesis development. Even if the given problems and context were not directly related to students' specific domain knowledge, it appears that domain knowledge can play a role as a predictor in the hypothesis development model. This is consistent with Alexander, Johnson, and Schreiber (2002), who report a similar finding from children's activities in developing alternative categories. Children with less content knowledge tend to use full examinations instead of developing hypotheses. On the other hand, children having an intermediate level of domain knowledge are more likely to use hypothesis development strategies as well as to produce correct answers. However, Alexander et al. (2002) mentioned that high domain knowledge in children does not completely explain the quality of hypothesis testing, because children tend to formulate a single hypothesis and attempt to seek only evidence that confirms their hypothesis, rather than adequately gathering enough sufficient information, generating various hypotheses, and being willing to disconfirm their hypothesis. The last hypothesis development behavior is related to the metacognitive processes of the problem solver.

In the present study, the results imply that young adolescents who have higher metacognitive abilities, as well as specific strategies and skills, showed better hypothesis-development performance in ill-structured problem solving, in fact, similar to adult problem solvers. The importance of the role of the metacognitive approach in hypothesis development is continuously pointed out by researchers examining hypothesis generating and testing processes (Bruner et al., 1956; Klayman & Ha, 1987; Osmo & Rosen, 2002; Skov & Sherman, 1986). As a set of cognitive processes, the hypothesis development process finds it necessary to use metacognition to solve problems and to deal with complex problems in the real world (Jones & Rivett, 2004). Especially, problem solvers in an unfamiliar or uncertain problem context will tend to inadequately consider relevant knowledge in the problem circumstance.

This study has theoretical and practical implications for educators. First, providing training in metacognitive strategies or knowledge for young adolescents might be useful as an intervention to enhance young adolescents' hypothesis-development performance in ill-structured problem solving challenges. For example, expert thinking processes (Ge & Land, 2004) or reflective prompts of the type that students used in the present study might be useful tools, based on the characteristics of novice problem solvers during the generation and evaluation of their hypotheses. Second, young problem solvers need to have relevant domain knowledge, similar to the way expert problem solvers process high domain knowledge and metacognition training. Even if problem solvers have enough domain knowledge, its effectiveness and usefulness in developing a hypothesis is influenced by the problem solver's regulation of their cognitive activities.

The understanding of factors influencing hypothesis performance, and the associations between these factors in predicting problem solvers' performance in problem-based learning is extended by the results of the present study. However, there are several considerations regarding limitations for the generalization of the results. First, participants might have all been highly motivated. Therefore, it might get different results with a different population. Second, the subjects of this study are Korean 6th-grade students. It may be necessary to apply this study to different ethnic groups first before generalizing the results. Third, the number of subjects was 101 students, which is a small subject size for structural equation modeling, as compared to the number recommended by Kline (2004), fifteen subjects per manifest variable. Therefore, the interpretations of results are limited to the present subject group.

CONCLUSIONS

The series of studies described in the present study was designed to investigate the influence that metacognitive scaffolds have on hypothesis development in ill-structured problem solving, as well as to advance progress toward a theoretical model including predictors for hypothesis-development performance in young adolescents.

This study provides preliminary evidence that metacognitive scaffolds can facilitate the support of metacognition for monitoring and evaluating hypothesis development of young adolescents in the sample. Scaffolding young student's metacognition influenced the hypothesis-development performance, including generating and evaluating hypotheses. Students who solved problems in the PBL module with metacognitive scaffolds performed significantly better in the development. Contrary to expectations, the results of both treatment and control group did not show a significant difference in solution-development performance. However, students' hypothesis-development performance has significant predictive power toward solution development. In future research, the development of an understanding of the use of metacognition in the sub-processes of hypothesis development will require substantial investigation with regard to how metacognition processes are related to hypothesis generation and evaluation.

In terms of roles of psychological predictors, it was interesting to note that high metacognition and prior domain knowledge tended to improve the results of hypothesis development. Surprisingly, the impact of young adolescents' motivation in academic tasks does not predict hypothesis development in ill-structured problem solving. Future research could focus on additional factors in the model to determine which are the more powerful factors that explain the hypothesis-development performance of young adolescents.

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APPENDIX A

CONSENT FORM

PARENT PERMISSION FORM

Influence of Metacognitive Scaffolding on Hypothesis Development in Ill-Structured Problem Solving

Your child has been asked to participate in a research study to investigate what the effects of metacognitive scaffolding on hypothesis development on ill-structured problem solving. Your child was selected to be a possible participant because your child is involved in a school satisfying research purpose. A total of approximately 200 people have been asked to participate in this study. The purpose of this study is to investigate the effect of metacognitive scaffolding on hypothesis development in ill-structured problem solving process and the relationships among background information, motivation, metacognition, domain knowledge, information literacy, and ill-structured problem solving performance.

If you agree to participate your child in this study, your child will be asked to complete five surveys and web-based problem solving activities. This study will take three times during the two weeks of study (total 45-minute class periods). The risks of participation in this study are that your child might be uncomfortable answering some of the questions asked. Your child is encouraged to discuss this with the researcher. The researcher will explain the questions to them in more detail. The benefits of participation are that your child will be contributing to a greater understanding for the role of hypothesis development in the ill-structured problem solving process by young adolescence.

This study is anonymous. The records of this study will be kept private. No identifiers linking your child to the study will be included in any sort of report that might be published. Research records will be stored securely and only by the researcher, Hye Jeong Kim. Your decision whether or not to participate will not affect your child's current or future relations with Texas A&M University. If you decide to participate, your child is free to refuse to answer any of the questions that may make your child uncomfortable. Your child can withdraw at any time without your child's relations with the University, Job, benefits, etc., being affected. You can contact the researcher Hye Jeong Kim, hjkim@neo.tamu.edu, 1-979-764-7876 or Dr. Susan Pedersen, spedersen@coe.tamu.edu, 1-979-458-1128 with any questions about this study.

This research study has been reviewed by the Institutional Review Board – Human Subjects in Research, Texas A&M University. For research-related problems or questions regarding subjects' rights, you can contact the Institutional Review Board through Ms. Melissa McIlhaney, IRB Program Coordinator, Office of Research Compliance, (979)458-4067, mcilhaney@tamu.edu.

Please be sure you have read the above information, asked questions and received answers to your satisfaction. You will be given a copy of the consent form for your records. By signing this document, you consent to participate in the study.

Child's Name____

Parent's Signature______________________________ Date________________

Researcher's Signature___________________________ Date________________

PARENT PERMISSION FORM (Korean)

보호자 동의서

비구조적 문제해결에서 가설개발에 대한 초인지스케폴딩의 영향에 관한 연구

안녕하십니까?
저는 미국 텍사스 A&M 대학교(Texas A&M University, College Station)의 교육심리학과 (교육공학전공) 박사과정에 재학중인 김혜정이라고 합니다. 6학년 학생들을 대상으로 한 연구활동에 보호자님의 자녀가 참여할 수 있도록 허락을 구하기 위해 말씀 여쭙습니다. 저는 실생활에서 학습자들이 접하는 문제해결과정에서 가설을 생성하고 정보를 바탕으로 검증하는 과정을 핵심단계 중 하나로 보고 있습니다. 그래서 학습자들이 문제해결을 할때 가설을 생성하는 능력을 확인하고 더불어 학습자들의 인지요인(사전지식, 초인지, 동기, 정보소양)과의 관계를 조사하고자 합니다. 본 실험을 위해 총 200여명이 참여하길 기대하고 있습니다. 부디 보호자님의 자녀가 연구에 참여할 수 있도록 허락 해주시길 부탁드립니다.

이 연구에 자녀의 참여를 허락하신다면 다섯가지 설문지(초인지, 사전지식, 컴퓨터경험, 정보소양, 동기)와 웹기반의 문제해결 활동(야생동물 전문 조사관:Animal Investigator)에 참여하게 됩니다. 본 연구는 총 3 회가 실시됩니다. 본 연구 참여의 좋은 점은 실생활 문제(비구조적 문제) 해결 과정에서 가설 개발 활동의 중요성을 조사하는 연구에 자녀가 기여 한다는데 있습니다. 학생들이 설문지상의 일부 질문을 이해하고 받아들이는 데 약간의 어려움을 느낄지도 모른다는 점은 연구자인 제가 충분히 인지하고 있으며 이 때는 해당 학생이 거리낌없이 연구자와 대화할 수 있으며 본 연구자는 학생들에게 해당 문항에 대해 자세히 설명을 할 것입니다.

본 연구는 익명으로 진행됩니다. 이렇게 수집된 연구자료는 비밀이 보장되는 곳에 보관될 것입니다. 보호자님 자녀 본인임을 확인할 어떠한 사항도 출판될 연구 보고서에 포함되지 않을 것입니다. 연구기록은 연구자만이 확인할 수 있는 안전한 장소에 보관이 될 것입니다. 참여 여부에 관한 결정은 후에 텍사스 A&M 대학교와의 어떠한 관계에도 영향을 미치지 않습니다. 학생들은 답하기 불편하게 느껴지는 질문에 대해서는 자유롭게 답변을 거부할 수 있습니다. 또한 여러분의 자녀는 어떠한 때라도 연구참여를 중단할 수 있습니다. 이 연구에 대해 질문이 있으시면, 저 혹은 담당 지도 교수인 수전 피터슨 박사의 이메일 주소나 전화로 연락하시면 됩니다.

연구자: 김혜정: hjkim@neo.tamu.edu, (미국) 1-979-764-7876, (한국) 02-704-7185 미국 주소311 Kyle Avenue, College Station, TX 77840
지도교수 : 수전 피더슨 박사(Dr. Susan Pedersen): spedersen@coe.tamu.edu, 1-979-458-1128

이 연구는 텍사스 A&M 대학교의 연구윤리심의위원회 (IRB: the Institutional Review Board – Human Subjects in Research)에 의해 심의 완료되었습니다. 연구와 관련된 문제나 연구 참여자의 권리에 관해 질문이 있으시면 IRB의 담당자에게 연락하시면 됩니다. 담당자는 Melissa McIlhaney이며 연락처는 다음과 같습니다. IRB Program Coordinator, Office of Research Compliance, (979) 458-4067, mcilhaney@tamu.edu.

위의 연구정보를 읽으시고 궁금한 점에 대한 만족스런 답을 얻으셨는지요? 이 동의서의 사본을 가지셔도 좋습니다. 이 문서에 서명하시는 것으로 여러분 자녀의 연구참여에 대한 동의가 이루어집니다.

학생 이름란____

보호자 서명란____ Date ___________________

연구자 서명란____ Date ___________________

APPENDIX B

PROBLEM SCENARIO OF ANIMAL INVESTIGATOR

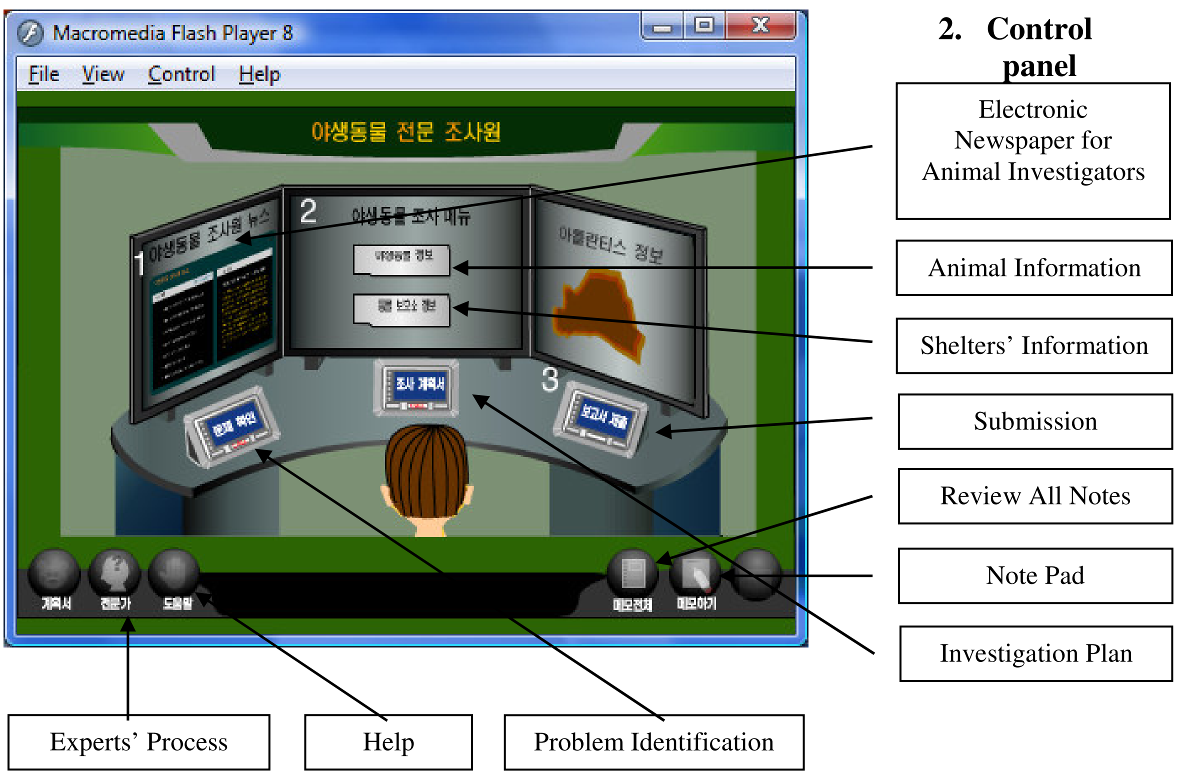
Animal investigator’s country and the Atlantis government have full diplomatic relations. Animal investigator’s country is interested in the future development of oil and gas near Atlantis Bay. Thus, both countries have established an official agreement about oil and gas extraction. An oil spill occurred at Atlantis Bay because an oil tanker hit a reef in Atlantis Bay. Animal investigator’s country has decided to dispatch a special team to help clean the oil spill as well as to help rescue animals harmed by the oil spill. The role of the animal investigator in the mission is to help allocate animals harmed by the oil spill to appropriate local animal shelters.

APPENDIX C

SCREEN CAPTURES OF ANIMAL INVESTIGATOR

1. Introduction

2. Control panel



3. Electronic newspaper

Close newspaper

Content example

Recently, a devastating oil spill occurred at Atlantis Bay. Our country's oil tanker departed from the oil terminal in the by, heading south. The oil tanker hit a reef, and the spilled oil is starting to spread in Atlantis bay.

News Title e.g.) 3. Oil spill near Atlantis Bay

4. Problem representation after reading newspaper

You already read news about the oil spills in Atlantis Bay. You were selected as an animal investigator to dispatch into Atlantis.

Please, send your statement about what is a problem for you to solve as an animal investigator. Please describe with related article number.

Back to electronic newspaper

Submit

5. Hypothesis development stage: animal information

Animal status

Additional Information

Write your response in word processing software

You may know who I am. Yes. I am a sea turtle. I am hungry. When I was young I loved to have vegetables in the sea. I am over fifty years old. Now I prefer to have both fish or invertebrate small animals like jellyfish, crab, or echinoid, #####. I feel so hungry.

6. Hypothesis development stage: shelters' information

Additional Information

Major species: lizard, crocodile,

Distance from oil spill area: about 1 hr with car

e.g.) Shelter's Features: It has many rare reptiles. They developed wet area in the zoo. It is close to the seashore. It has the facility to change from saltwater to fresh water. It is famous which can decorate the design in efficient way.

7. Solution Development Stage

Selecting best shelter for the sea turtle.

Describe the reasons of selecting the shelter as much as they can.

Submit a solution

8. Reflective Prompts for Treatment Group

Reflective Prompts

9. Expert self-

questioning process

for treatment group

Experts' questioning

10. Notepad and

review board

Review All Notes

Note Pad

APPENDIX D

STUDENT'S RESPONSE FORM AND A SAMPLE OF A STUDENT'S REPORT

1. Please use clues from the animal shelters and the animal information to complete the following sentence.

- If the animal (A) can go into the animal shelter (B), then the animal may stay well because (C). [a]

A: clues from the animal information, B: clues from the animal shelter, C: your explanation from your investigation.

2. According to your investigations, please report your final decision for the animal using the following the guidance sentence in detail.

- According to my investigation, the animal shelter (A) is the best shelter for this animal. I will send this animal (B) to the animal shelter because (C).

A: the name of the animal shelter, B: clues from the animal information, C: develop your reason according to your investigations.

Note. a. For second response, five guidance sentences are given to the students.

Sample of a student's report

Animal investigator's report

Based on clues from animal and local shelter's information, please find clues and develop possible solutions. Please carefully the guidance sentences and complete possible solutions

If the animal (*animal's condition*) can be sent to animal shelter, (*name of the shelter*), in (*shelter's conditions*) then the animal will stay well. Because (*describe why you think it works*)

1. If the animal (being hurt and laying eggs) can be sent to animal shelter, (2), in (abundant food, most similar with the place which sea turtle lived in, and no enemy), the animal will stay well because (the turtle has to be sent to a shelter as fast as possible because of getting hurt. The shelter, 2, is close to here. The habitat has abundant food and the most similar place with the turtle's habitat. It is best place to lay eggs.).

2. If the animal (being hurt and laying eggs) can be sent to animal shelter, (4), in (abundant jellyfish), the animal will stay well because (it can be cured quickly in the shelter in 1 hour only. And there are more abundant jellyfish, one of the turtles' foods, than other shelters. However, there are turtle's enemy, killer whales and great white shark. So turtle need to be isolated from them).

3. If the animal (being hurt and laying eggs) can be sent to animal shelter, (2), in (abundant food, most similar with the place which sea turtle lived in, and no enemy), the animal will stay well because (the turtle is getting hurt now. So the turtle has to be sent to a shelter as fast as possible. Shelter 2 is close to the oil spill area. There are abundant foods and similar with the turtle's habitat. It is most appropriate place to lay eggs. It will adapt to shelter 2.).

4. If the animal (being hurt and laying eggs) can be sent to animal shelter, (5), in (having veterinarians), the animal will stay well because (this sea turtle got hurt seriously. In this shelter, veterinarians can cure the sea turtle even though the location is far from the oil spill area. But there is a natural enemy, shark. So the sea turtle is supposed to be isolated from them).

5. If the animal (being hurt and laying eggs) can be sent to animal shelter, (3), in (offering a facility laying eggs), the animal will stay well because (eggs can be broken and baby sea turtle in the eggs can die if the sea turtle sent to the place which does not offer a hatching facility. Therefore if the sea turtle can go to shelter 3 offering a perfect environment for laying eggs, it will adapt well).

What is your solution based on above your possible solutions? Please describe why you think so with the most appropriate shelter for this animal.

This sea turtle can stay well in the shelter 2 because now the turtle got hurt. Shelter 2 is close to the oil spill area and there is abundant food for it. It is most similar with the sea turtle's habitant. It is most appropriate shelter for laying eggs. Therefore turtle can adapt well in shelter 2. In addition, shelter 2 has a facility for breeding animals and the turtle can lay eggs without a crowd.

Sample of a student's report

동물 조사원 활동 보고서

주어진 동물의 정보와 야생동물 보호소 정보에서 여러분이 찾은 단서를 이용하여 여러가지 해결방법을 찾아서 아래에 적어보세요. 먼저 아래 예문을 살펴보고 문장을 완성시켜 보세요.

만약에 (이 동물의 정보에서 찾은 단서 입력하는 곳) 구조된 동물이 (동물보호소 정보에서 찾은 단서 입력하는 곳) 동물 보호소 (번호)에 간다면 잘 지낼 수 있을 것이다. 왜냐하면 (왜 그렇게 생각하는지 써보세요.)

1. 만약에 (부상을 입고 곧 알을 낳을 것 같은) 바다거북이가 (먹이가 풍부하고 거북이가 사는곳과 가장 비슷하며 천적도 없는) 동물 보호소 (2)에 간다면 잘 지낼 수 있을 것이다. 왜냐하면 (거북이는 지금 부상을 입고 있으므로 빨리 보호소로 보내야 한다.보호소 2 는 거리도 짧고 먹이가 풍부하며 서식지와 가장 비슷하고 번식하기 가장 알맞은 보호소 2 로 보내면 잘 적응할것이다.).

2. 만약에 (부상을 입고 곧 알을 낳을 것 같은) 바다거북이가 (해파리가 풍부한) 동물 보호소 (4)에 간다면 잘 지낼 수 있을 것이다. 왜냐하면 (차로 1 시간 정도만 떨어져 있어서 빨리 치료를 할수 있을것이다.그리고 바다거북이의 먹이인 해파리가 다른 보호소보단 훨씬 많기 때문이다.하지만 보호소 4 엔 바다거북이의 천적인 범고래와 백상어가 있기 때문에 어느 기간동안은 격리 해 놓아야 할 것이다.).

3. 만약에 (부상을 입고 곧 알을 낳을 것 같은) 바다거북이가 (먹이가 풍부하고 거북이가 사는곳과 가장 비슷하며 천적도 없는) 동물 보호소 (2)에 간다면 잘 지낼 수 있을 것이다. 왜냐하면 (거북이는 지금 부상을 입고 있으므로 빨리 보호소로 보내야 한다.보호소 2 는 거리도 짧고 먹이가 풍부하며 서식지와 가장 비슷하고 번식하기 가장 알맞은 보호소 2 로 보내면 잘 적응할것이다.).

4. 만약에 (부상을 입고 곧 알을 낳을 것 같은) 바다거북이가 (전문 수의사가 있는) 동물 보호소 (5)에 간다면 잘 지낼 수 있을 것이다. 왜냐하면 (바다거북이는 지금 심각한 부상을 입고 있기 때문에 멀리 떨어져 있지만 확실한 치료를 할수있기 때문이다. 하지만 바다거북이의 천적인 상어가 있어서 마찬가지로 어느기간동안은 격리 해놓아야 할 것이다.).

5. 만약에 (부상을 입고 곧 알을 낳을 것 같은) 바다거북이가 (알을 낳을 환경이 갖춰져 있는) 동물 보호소 (3)에 간다면 잘 지낼 수 있을 것이다. 왜냐하면 (지금 바다거북이는 알을 낳을 장소가 갖춰져 있지 않은 보호소에 가면 알이 깨지거나 알안에 있는 새끼들이 죽을수도 있기 때문이다.그러므로 알을 낳을 환경이 완벽히 갖춰져 있는 보호소 3 에가면 잘 적응 할수 있을 것이다.).

위의 해결방법 중 여러분이 생각하는 가장 적합한 동물보호소의 이름과 왜 그렇게 생각하는지 자세히 적어주세요.

이 바다거북이를 동물 보호소 2 에 보내면 가장 잘 지낼 수 있을 것이다. 왜냐하면,거북이는 지금 부상을 입고 있으므로 빨리 보호소로 보내야 한다.보호소 2 는 거리도 짧고 먹이가 풍부하며 서식지와 가장 비슷하고 번식하기 가장 알맞은 보호소 2 로 보내면 잘 적응할것이다.그리고 보호소 2 는 번식하는 동물들이 사람들을 피해 알을 낳을수 있는 장소가 있기 때문이다.

APPENDIX E

RUBRIC SYSTEM FOR ASSESSING PROBLEM-SOLVING PERFORMANCE ON ILL-STRUCTURED PROBLEM

Process	Maximum score	Description
Hypothesis Development		
	1	Relates to the problem
Generation	2	Generates hypothesis based on multiple pieces of evidence
	1	Develops a logical statement
Evaluation	1	Supports a hypothesis with given information
	2	Develops evaluation of hypothesis
Solution Development		
	1	Proposes a solution from the hypothesis developed
Generation	2	Develops a solution with explicit explanation
	1	Develops a logical solution statement
	1	Analyzes problem situation and constraints
	2	Provides relevant evidence
Evaluation	2	Develops a valid argumentation
	1	Identifies explicit consideration of decision criteria

Note. The score for hypothesis-development performance was given per each hypothesis developed and the final grade was determined by score summation.

VITA

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