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Factors Affecting Earth Science Problem-Solving Performances of Elementary School Pre-service Teachers: A Study on the Motions of the Moon and the Planets

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Abstract: The aim of this study was to investigate the factors affecting earth science problem-solving performances of elementary school pre-service teachers. The participants of the study were 81 students attending an elementary school teacher education university. The instruments of the study were paper-and-pencil tests, questionnaires, and interviews. The tests mainly measured the participants' problem solving abilities in the motions of the moon and the planets. Correlation and multiple regression techniques were used for data analysis. The results demonstrated that the pre-service teachers' problem solving abilities were low. Problem-solving performances were affected by the procedural knowledge, the participants' perception of the past earth science performance, self-efficacy, and the prerequisite declarative knowledge. Contrary to our expectation, the spatial visualization ability was not found to be related to the problem-solving performances. Implications of the study are drawn, and suggestions are made for further research.

Key words: problem solving, science education, pre-service teachers, procedural knowledge, self-concept, self-efficacy, spatial visualization ability, the Moon, the Solar System, Planets

INTRODUCTION

Together with the sun, the moon is a celestial body familiar to all students, and the motion of the moon is taught in the elementary and middle school science classes. And yet, the motions of the moon and the planets are one of the areas that Korean students have the greatest difficulty among the areas of earth science. Studies on the students' understanding of the motions and phases of the moon indicate that students fail to acquire a scientific understanding even after learning the concepts in school (Jeong, 1996; Jeong, 1991; Chae, 1996). Min (1991) and Vosniadou (1991) showed that even adults have difficulty in understanding the phases of the moon.

A more serious problem is that the pre-service teachers have a rather poor ability to solve the problems related to the motions of the moon and the planets. The pre-service teachers for elementary school were especially poor in such problem solving tasks (Myeong, 2001). Lack of competence on the part of the pre-service teachers has a negative effect on their confidence and attitudes, which in turn has an adverse effect on the students' problem-solving abilities. In fact, findings of the Third International Mathematics and Science Study-Repeated (TIMSS-R) indicate that Korean science teachers generally lack confidence in teaching science, especially teaching the topic of solar system (Martin *et al.*, 2000). Chae's (1996) study also shows that students believed their misconceptions about the astronomy were teacher-induced. Research efforts should be made to improve the pre-service teachers' problem-solving abilities in order to stop this vicious cycle. And yet, there have been only a few studies with pre-service teachers (Min, 1991; Myeong, 2001), although there have been some studies done with the students (Chae, 1996; Jeong, 1991; Jeong, 1996; Kim and Lee, 1996; Lim and Kim, 1994; Sharp, 1996).

Among the sub-areas of the earth science subject, the motions of the moon and the planets are the most difficult to the students. The reasons for the difficulty may be related to the lack of spatial visualization ability and confidence, insufficient

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prerequisite knowledge, and inattentiveness in science classes (Anderson, 1881; Ault, 1994; Baker, and Piburn, 1997; Gagne *et al.*, 1993; Kim, and Lee, 1996; Lim and Kim, 1994).

Much of the research up to date has been about the misconceptions or the degree of conceptualization; no research has been conducted on the variables related to problem solving. Research is needed on the variables deemed to be related to earth science problem-solving abilities, such as spatial visualization ability, confidence, and prerequisite knowledge. This study thus attempts to identify, with elementary school pre-service teachers, variables believed to be related to the problem solving and important predictors *when other variables are controlled.* The study is expected to provide some useful insights for the development of effective teaching strategies.

Research Questions

The research questions of the present study are as follows.

(1) How well do the elementary pre-service teachers in the study solve the problems about the motions of the moon and the planets?

(2) Is there any relationship between the independent variables such as spatial visualization ability, perception of past earth science achievement, self-concept in astronomy, self-efficacy, prerequisite declarative knowledge, and procedural knowledge and the dependent variable of problem-solving task performance by pre-service elementary school teachers?

(3) Of the six variables of spatial visualization ability, perception of past earth science achievement, self-concept, self-efficacy, declarative knowledge, and procedural knowledge, which variables significantly affects the problem-solving task performance when other variables are controlled.

REVIEW OF LITERATURE

The theoretical background of the present study is found in the theories of problem solving and understanding of the motions of the moon and the planets.

Prerequisite Declarative Knowledge and Proceduralization

With the growing recognition, in education and cognitive psychology, of the importance of problem solving, a lot of research has been conducted in this area in the last couple of decades. Research shows that expert and novice problem solvers have different prerequisite knowledge structures. Successful solvers have sufficient and well-organized prerequisite knowledge, while unsuccessful solvers have insufficient and poorly organized knowledge structures (Babara and Rubba, 1993; Gagne *et al.*, 1993; Myeong, 2001; Okey & Gagne, 1970; Noh *et al.*, 1996). According to Myeong (2001), Korean pre-service teachers were lack the prerequisite declarative knowledge to understand the motions of the moon and the Planets.

Problem solving requires not only declarative knowledge but also an understanding of the conditions *for the application of such knowledge and the* ability to actually apply the knowledge. Unsuccessful problem solvers may have necessary prerequisite knowledge of the concepts and principles for the task, and yet they may fail to activate the declarative knowledge (Kim, and Lee, 1996; Lim and Kim, 1994; Myeong, 2001). Knowing when and how to apply the declarative knowledge and the actual application of such knowledge constitute the procedural knowledge. Expert problem solvers are found to have such procedural knowledge (Babara and Rubba, 1993; Gagne *et al.*, 1993; Myeong, 2001). Myeong (2001) found that Korean pre-service teachers failed to solve problems related to the motions of the moon and the planets because they did not know when and/or how to apply their existing knowledge.

Self-Efficacy

Past experience of repeated failures in solving problems about the motions of the moon and the planets can lead to the loss of self-confidence in such topics. Self-confidence was found to affect students' attempt to solve the problems, the amount of time they put in, and their behaviors when faced with challenges (Bandura, 1986; Gagne *et al.*, 1993). The results of the TIMMS-R (Martin *et al.*, 2000) show that students performed worst in these topics of earth science. Korean science teachers' confidence is also low in this sub-area of earth science. Only 22% of Korean science teachers feel very confident in their preparation of teaching such topics (particularly about the solar system and the universe).

Recently, researchers have distinguished between two kinds of confidence: self-concept and self-efficacy (Bandura, 1986; Pajares and Miller, 1994). Self-concept is a broader, general confidence, while self-efficacy is a task-oriented, specific confidence. In mathematics, self-efficacy was found to account for the mathematic problem solving ability more than self-concept does (Pajares and Miller, 1994). In the present study, the term 'self-concept' refers to the overall confidence in astronomy and the term 'self-efficacy' refers to the task-oriented specific confidence.

Spatial Visualization Ability

One of the reasons for the students' difficulty in understanding the motions of the moon and the planets has to do with their two-dimensional understanding of the motions. Understanding varying phases and motions of the moon and the planets requires an understanding of the cause-effect relationships of the motions and changes of the celestial bodies in three dimensions. Spatial visualization skills are necessary to understand the phenomena in the space (Ault, 1994; Baker and Piburn, 1997).

METHOD

The Subjects

The study involved 81 freshmen from a national university of education, an elementary school teacher education university, in the Seoul Metropolitan area. The students' majoring areas were as follows:

Physical Education	18
Fine Arts Education	20
Music Education	19
English Education	24
Total	81

Instruments

The study used three types of instruments: paper-and-pencil tests, questionnaires, and interviews. The tests and the questionnaires were the main instruments of data gathering, and the interviews were used to supplement the test results when the subjects' use of procedural knowledge was not evident in the test responses or when two raters interpreted the responses differently. There were eleven cases that required interviews.

The variables included in the present study were problem-solving performance scores as a dependent variable, and prerequisite declarative knowledge, procedural knowledge, self-concept, self-efficacy, the subjects' perception of their past earth science performance, and spatial visualization ability as independent variables. Test items and questionnaires were developed to tap into these variables.

Four items measured the subjects' problem solving abilities, with two items for the moon and two for the Venus. Each item required the subjects to identify the phases, time, and direction (bearings). Each task of an item was assigned 1 point; the total points thus were 12 points. The question was an open-

Table 1. Categories and numbers of items for the problem solving tasks and declarative knowledge measures

Content	Number of items (Score)
I. Problem Solving	(12)
Moon (phases, time, direction)	2 (2×3 = 6)
Venus (phases, time, direction)	2 (2×3 = 6)
II. Declarative Knowledge	(8)
Earth's direction of rotation	1 (1)
Earth's period of rotation	1 (1)
Moon's direction of revolution	1 (1)
Moon's period of revolution	1 (1)
Reason for the moon, stars, & the planets rising	1 (1)
Reason for Moon's phase changing	1 (1)
Shapes of the Moon visible to the earth' observer	1 (2)

ended response type, consisting of three parts. The first part asked the participants to either draw a figure or write words associated with the given test item. The second part asked the participants to actually solve the problem. The last part asked the participants to redescribe the problem solving process if it was not fully described in the second part.

Prerequisite declarative knowledge was measured through open-ended statement type questions, except for an item of the phases of the moon. There were 6 items of this type with 1 point assigned to each item. The item of the phases of the moon was assigned 2 points. A partial point of 1 was given if only one of the two possibly correct options was selected.

The same items were used to gather information about the procedural knowledge. Procedural knowledge was measured by the evidence of the use of declarative knowledge in the process of solving the problems described above. Since the problem solving required a stream of reasoning and utilization of existing knowledge, the participants were asked to demonstrate this process verbally or graphically. If the answer sheets showed traces of such reasoning and declarative knowledge utilized, 1 point was given. The item about the phases of the moon was assigned 2 points, as it required the participants to actually draw the visible portion of the moon seen by terrestrial observer.

Five-point Likert-type scales were used in questionnaires to measure the participants' perception about their past earth science performance, their self-concept about their performance in astronomy, and their self-efficacy in specific problem solving tasks. The scale for the participants' perception about their past earth science performance ranged from 1 (very poor) to 5 (very good). The scale for the self-concept about the performance in astronomy ranged from 1 (not confident at all) to 5 (very confident). The same scale was used for self-efficacy measurement. There were one scale for the self-perception, one scale for self-concept, and four scales for self-efficacy (one for each of the four problems on the moon and the Venus). The mean point for the self-efficacy was obtained from the four scales.

A short version of the Purdue Visualization of Rotations Test (Bonder & McMillan, 1986) was used to measure the spatial visualization ability. There were 20 test items in the test, with 1 point for each item. Testing time for this short version was 10 minutes.

All instruments except for the Purdue Test were developed by the researcher, in the following procedures.

(1) Items development based on library research and pilot surveys.

(2) Content validation by experts

(3) Confirmation of test items understanding by the participants

(4) Revision of the test items

(5) Validation of face validity by three earth science teachers, two astronomy professors, and one testing specialist.

Procedure of Data Collection

Data were collected in the first session of the earth science class in the fall semester of 1997. The participants' spatial visualization ability, self-perception about their past performance in earth science, their self-concept about astronomy in general, and their prerequisite declarative knowledge were measured first, followed by the measurement of their self-efficacy. Then, a practice session followed for about 15 minutes, during which time the participants solved sample problems while describing their problem solving processes through a think-aloud method. Then actual problem solving tasks were given. After the problem solving session, the participants were asked to refine their descriptions of the problem solving processes.

Interviews

Interviews were done during and after the paper-and-pencil tests. The purpose of the interviews was to gather supplementary information to clarify the responses. During-the-session interviews were done by the researcher who moved about the classroom asking the participants to clarify their responses or to do the task again, if necessary, through the think-aloud method. After-the-session interviews were done with individual students when the raters found the responses needed further clarification.

Data Analysis

The data was analyzed using Microsoft Excel and SPSS 9.0 statistical program. Microsoft Excel was used to calculate correct response rates; SPSS 9.0 was used to calculate the means and standard deviations of the variables, correlations, and multiple regression coefficients.

THE RESULTS AND DISCUSSION

The rates of correct responses of the participants are presented below, followed by the correlations between each of the independent variables and the problem-solving performance, and the strength of predictability of each variable for the problem-solving abilities. In counting the correct responses, the final output was judged for its correctness without a consideration of the problem-solving process.

The Rates of Correct Responses

The rates of correct responses were generally low for the test items on the moon and the Venus. Table 2 shows the correct response rates for the phases of the moon and the Venus, the possible time of observation, and for the bearings at the time of observation. For the item about the moon, the correct response rates were 60% for the phase, 33% for the observable time, and 20% for the bearings. In the case of the Venus, 74% of the subjects were correct on the phase, 58% on the observable time, and 41% on the bearing. The participants generally performed more poorly on the observable time and bearings than on the phases. This result concurs with Myeong's (2001) study result. In both studies, the pre-service teachers did not differentiate between their general perspective of the bearings in the daily life and the scientific perspective of the bearings required for the earth science problem solving.

The participants scored higher on the items about the Venus than on the items about the moon. One possible reason for the higher score is the length of interval between the time of learning and the time of testing. The moon was taught in middle school, while the Venus was taught in high school. As a result, the participants may have a more fresh memory about the Venus than about the moon. Besides, the Venus is often tested upon in the College Scholastic Ability Test.

Table 2. Percentage of correct responses of each item on the problem solving performance measures

Item	Moon			Venus		
	Waxing crescent	Last quater	Total	West greatest elongation	East greatest elongation	Total
Phases	60	60	60	78	69	74
Time	38	27	33	68	49	58
Bearings	20	19	20	54	27	41

Associations Among Variables

The means, standard deviations, and Pearson product-moment zero-order correlation coefficients of the variables were calculated first. Table 3 presents these statistics. The mean number of the successfully performed problem-solving tasks was 5.75 out of 12. The mean of the spatial visualization ability was

Table 3. Means, standard deviations, and zero-order correlations of variables in the Multiple Regression Analysis

Variables	Mean (SD)	1	2	3	4	5	6	
1. problem solving	5.75 (2.95)	–						
2. spatial-visualization	15.00 (2.85)	.00	–					
3. past achievement	3.52 (0.78)	.31**	.06	–				
4. self concept	2.42 (0.86)	.27*	.23*	.44**	–			
5. self efficacy	2.22 (0.92)	.52**	.12	.28*	.43**	–		
6. declarative knwlge.	5.09 (1.86)	.48**	.15	.02	.35**	.34**	–	
7. procedural knwlge.	3.47 (1.98)	.57**	.05	.01	.22*	.39**	.52**	–

*Correlation is significant at the .05 level (2-tailed).

**Correlation is significant at the .01 level (2-tailed).

15.0 out of 20. The mean of the participants' perception of past achievement in earth science was 3.52 on the 5-point scale. The mean of the self-concept regarding astronomy was 2.42, and the mean of the self-efficacy regarding the motions of the moon and the planets was 2.22 on the 5-point scale. Although the self-concept about astronomy and the self-efficacy about the motions of the moon and the planets were associated with each other ($r = .43$), the self-efficacy was a little lower than the self-concept. The subjects were more confident with the Venus than with the moon, which corresponds with their higher scores in the Venus items than in the moon items.

The mean score of the declarative knowledge was 5.09, while the mean of the procedural knowledge was 3.47, indicating that the pre-service teachers failed to fully proceduralize their declarative knowledge in the problem-solving situations. They did not seem to know when and how to use in problem situation what they know cognitively. This result concurs with previous studies (Jeong, 1996; Myeong, 2001), which showed the subjects failed to solve problems because they could not generalize the knowledge pertaining to one particular task to other tasks.

To determine the strength of the relationships between the dependent variable (problem solving performance) and independent variables, zero-order correlation coefficients between them were calculated, as presented in Table 3. As expected, all of the independent variables (predictors) except for spatial visualization ability were significantly correlated with the dependent variable. The correlation of the participants' perception of their past performance in earth science and their actual problem solving performance level was significant ($r = .31$). The performance success rate was also significantly related with the self-concept about astronomy ($r = .27$), self effiicacy ($r = .52$) the prerequisite declarative knowledge ($r = .48$), and with the procedural knowledge ($r = .57$). Contrary to our expectation, spatial visualization ability was not related to the problem-solving performance ($r = .00$).

Table 4. Significance test of the multiple regression: Analysis of variance (ANOVA) results

Model	Sum of Squares	df	Mean Squares	F	sig.
Regression	364.29	6	60.72	13.58	.000
Residual	330.78	74	4.47		
Total	695.06				
R=0.72			R^2=0.52		

The Strength of Predictability

The zero-order correlation coefficients presented above show the degree of associations between the independent variables and the dependent variable. Since the independent variables themselves are also interrelated, the zero-order correlation coefficients do not tell us exactly how well each independent variable (predictor) alone can predict the dependent variable (criterion) when other independent variables are controlled. Multiple regression analysis was thus used to determine the strength of predictability of each predictor. A test of full regression model was conducted (Table 4). Predictors were found to collectively contribute to the prediction of problem solving performance ($p<.000$), accounting for 52% of the variance of the performance of problem solving.

A standardized regression coefficient (beta weight) in multiple regression analysis indicates the amount of increase or decrease in the dependent variable for a one-unit difference in an independent variable when other independent variables are controlled. As shown in Table 5, the best predictor was the procedural knowledge ($\beta = 0.38$), followed by the perception about past performance in earth science ($\beta = 0.29$), self-efficacy ($\beta = 0.27$), and prerequisite declarative knowledge ($\beta = 0.25$). The self-concept

Table 5. Standardized coefficients (β) of each predictor in the multiple regression analysis

Predictors (Model)	Standardized Coefficients (β)	t	Sig.
spatial-visualization ability	−0.06	−0.79	0.430
past achievement	0.29**	3.17	0.002
self concept	−0.12	−1.20	0.232
self efficacy	0.27**	2.77	0.007
declarative knowledge	0.25*	2.46	0.016
procedural knowledge	0.38**	3.77	0.000

*p<0.05, **p<0.01.

in astronomy, which showed some degree of correlation with the problem solving performance ($r = .27$), did not have any contribution to the prediction of the problem solving performance. In fact, the beta coefficient was in a negative number, although it was not statistically significant.

CONCLUSION AND IMPLICATIONS

The present study investigated pre-service teachers' problem-solving performances in the tasks related to the motions of the moon and the planets. The participants were 81 freshmen students in an elementary school teacher education university.

Major Findings

Major findings are as follows: First, the pre-service teachers' scores on the tests about the moon and the Venus were low. They scored higher on the tests about the Venus than on the test about the moon. The result concurs with Myeong's (2001) study result. The effect of different memory spans was speculated as a possible reason for the difference.

Second, all independent variables except for the spatial visualization ability were found to be positively correlated with the dependent variable (problem-solving performances). These independent variables include the perception of the past earth science performance, self-concept about astronomy, self efficacy, prerequisite declarative knowledge, and procedural knowledge.

When other independent variables were controlled, procedural knowledge ($\beta = 0.38$), the perception of the subjects' past performance in earth science ($\beta = 0.29$), self efficacy ($\beta = 0.27$), and the prerequisite declarative knowledge ($\beta = 0.25$) were found to be strong predictor variables. The independent variables collectively accounted for 52% of the variance of the problem-solving performances.

Educational Implications

Educational implications are drawable from the findings: First, prerequisite declarative knowledge was found to be an important factor in successful problem solving. When teaching the motions of the moon and the planets, it is necessary to investigate the students' prior knowledge and misconceptions before presenting the tasks of learning.

Second, procedural knowledge was found to affect problem solving significantly. Pre-service teachers were generally incapable of proceduralizing their declarative knowledge. Carefully designed instructions and practice are necessary to help them to proceduralize their declarative knowledge.

Third, self-efficacy was also important in successful problem solving. Special strategies and efforts are needed to enhance prospective teachers' self-efficacy. The enhanced self-efficacy of the teachers in turn will improve the students' problem-solving abilities. This area promises a good research topic, as there has not been much research on this topic in earth science education,

Some Areas of Further Research

Some areas of further research can be identified from the present study: First, spatial visualization ability was found to be unrelated to the problem-solving performance in the present study. This might be because the participants of the present study were a homogeneous group sampled from one university. Further research with heterogeneous groups may produce different results.

Second, the independent variables in the present study may have affected the performance in different ways, depending on their interrelationships. Some independent variables might have affected the performance indirectly through other independent variables. A path analysis may be necessary to clarify the possible direct and indirect cause-effect relationships among the variables.

Third, further research is necessary to explain the 48% of variance of the problem-solving performance that was not accounted for by the independent variables.

Thus, the present study provided some useful knowledge about the state of the pre-service teachers' understanding of some important concepts in earth science, and about the relationships among various factors affecting their problem-solving performances in earth science, as well as insights for future teaching and research.

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