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A New Approach to the Science Education Assessment Using Partial Credits to Different Science Inquiry Problem Solving Process Types

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Abstract: Reasonable and reliable assessment method is one of the most important issues in science education. Partial credits method is an effective tool for assessing students' science inquiry problem solving. The purposes of this study were to classify the problem solving types based on the analysis of the thinking process, and how much the related science concept and the science process skills were used in solving science inquiry problems, and to describe the possibility and rationality of the assessment method that gives partial credit. 128 high school seniors were selected and their answers were analyzed to identify science concepts they used to solve each problem, and the result was used as the criterion in the scientific concept test development. Also, to study the science inquiry problem solving type, 152 high school seniors were selected, and protocols were made from audio-taped data of their problem solving process through a think-aloud method and retrospective interviews. In order to get a raw data needed in statistical comparison of reliability, discrimination and the difficulty of the test and the production of the regression equation that determines the ratio of partial credit, 640 students were selected and they were given a science inquiry problem test, a science process skills test, and a scientific concept test. Research result suggested it is more reasonable and reliable to switch to the assessment method that applies partial credit to different problem solving types based on the analysis of the thinking process in problem solving process, instead of the dichotomous credit method.

Key words: *science inquiry problem, science concept, science process skills, thinking process, think-aloud, protocol, partial credit, dichotomous credit method, reliability, discrimination, difficulty.*

INTRODUCTION

Many science educators and cognitive psychologists pointed out that the scientific knowledge consists of procedural knowledge and declarative knowledge which is the ultimate result of the procedural knowledge. Procedural knowledge refers to the basic and general science process skills that are extremely content-free from outer conditions in our thinking process (Lawson, 1982), and declarative knowledge refers to content-specific scientific concepts that tend to adjust appropriately to outer situations in our thinking process (Ausubel, Novak and Hanesman, 1978; Novak, 1977).

These two knowledges are essential to solve any kind of scientific problem, and if these two knowledges are not satisfied with each other, or if one of these knowledges is lacking, the problems are cannot be solved (Lawson, 1982; Mayer, 1983). With this perspective, many science educators have long been working on research and development of test methods to measure science process skills (Burns, Okey and Wise, 1985; Dillashaw and Okey, 1980; Ludeman, 1975; Moliter and George, 1976; Matthesis, Nakayama, Pottenger and Jones, 1988; Smith and Welliver, 1990; Tannenbaum, 1971; Burns, 1972), and most of them are made up of multiple choice items, which consist of either the correct answer type item or the best answer type item.

These tests of science process skills are limited tests of subcategories such as basic science process skills and integrated science process skills. Furthermore, even though most of science inquiry problems are

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※This study was completed in succession to The Influence of Science Process Skills and Concepts Understanding on the Earth Science Problem Solving in College Scholastic Ability Test(Lee, H.R, 1988, Doctoral Dissertation, The Korea National University of Education) structured to be solvable only when we apply both science process skills and scientific concepts, it has been pointed out that these tests are also using the correct answer type of multiple choice item tests uncritically (Hopkin, Stanley and Hopkins, 1990).

It is a very difficult task to organize alternatives or wrong answers when producing multiple choice item tests. Particularly, the development of the correct answer type item test in which only one is definitely right answer and the others must be wrong based on a specific science theory or view is an extremely difficult project.

Carefully reviewing the correct answer type item tests that are developed to have only one correct answer among the five choices, we can find that they are tend to be different from developer's original intention. When other paradigms and theories apply them, many of the tests tend to have more than two correct answers, which are the best answer type item tests.

Actually it is much easier to develop the best answer type items technically from all answers which can be correct by choosing "the most probable" or "the most correct" answer. If the best answer type items are substituted for the correct answer type items, the item itself would not have any deficiency and the problems encountered with correct answer type items could be get rid of. But in the case of the best answer type items, the irrationality issue in assessment can be a serious problem unless we give a partial score or credit system.

That is, because two or all correct answers are included in the best answer type items, it is not appropriate to give dichotomous scores; one score is given when an answer that has more information and knowledge than others is selected, a zero score when the other is selected.

In these days, most science achievement tests are the type of best answer items with which we can measure the integrated problem solving ability that is possible only when the science process skills and related science concepts are applied together. Considering the reality of this type of science learning assessment and the theory that says we have to apply a partial credit system when making multi-answer type items as well as the best answer type items in the science learning achievement tests (Glass and Verhelst, 1989; Green, Crone and Folk, 1989; Hopkins, Stanely and Hopkins, 1990; Master, 1988; Koch and Dodd, 1989), the dichotomous assessment method also turns out to be invalid and logically conflicting.

The purposes of this study were to classify the problem solving types based on the analysis of the thinking process, and how much the related science concept and the science process skills were used in solving the science inquiry problems, and to discover the possibility and the validity of the assessment method that gives partial credit.

METHOD

Sampling and Research Design

Stratified sampling is used at an large urban high school participated in the study. Students had no previous experience testing in science concepts and process skills. Their socioeconomic status is high.

To develop a scientific concept test consisting of science concepts necessary to solve science inquiry problems, 128 high school seniors were selected and instructed how to solve the problems in tests. Answers in the tests were analyzed to select science concepts they used to solve each problem, and the result was used as the criterion in the scientific concept test development. Also, to study the science inquiry problem solving type, 152 high school seniors were selected, and protocols were made from audio-taped data of their item solving process through a think-aloud method and retrospective interviews. In order to get a raw data needed in statistical comparisons of reliability, discrimination and the difficulty of the test and the production of the regression equation that determines the ratio of partial credit as per different science inquiry problem solving types, 640 students were selected and they were given a science inquiry problem test, a science process skills test, and a scientific concept test.

The science inquiry problem test and the science process skills test consisted of 20 items respectively, and the scientific concept test consisted of 49 items. In particular, special attention was paid to avoid double use of sample students in other tests in order to reduce the repetition effect of tests, and both qualitative and quantitative study methods were applied.

RESEARCH PROCEDURES

Development and Selection of the Test

Developing science inquiry problem test that is solvable only when both science process skills and science concept are applied together. The science inquiry problem test consists of total 20 items, five items are respectively given to each category, these are ability to recognize the problem and to establish hypothesis, ability to design and execute experiments, ability to interpret and analyze data, and ability to draw a conclusion and generalization. TIPS (Dillashaw and Okey, 1980) was used in the science process skills test. In addition, a concept test is developed in order to measure achievement of the science concept that is needed in solving each problem of the science inquiry test. This test has a total of 49 items, to solve each science concept item, it is necessary to provide an item at least to six items at most. To establish the validity of the science inquiry problem test and science concept test, six content experts examined. The results of the content validity index were 98%, 97%, respectively(by SPSS/PC$^+$10.1).

Protocol Development and Classifying Problem Solving Type

Protocol was made from audio taped data of the thinking process of the 152 subjects in the science inquiry problem test through the thinking aloud method. And follow-up retrospective interviews were done when the audio taped data proved to be unclear (Larkin and Rainard, 1984). The completed protocol was then classified into problem solving types based on the science process skills and the applied extent of science concepts needed to solve science inquiry problems (Table 1). In establishing the problem solving types classification, six different code values were applied with reference to the research of Barba & Rubba (1993).

Formulating the Regression Equation to Determine Partial Credit Ratio

Six hundreds and forty students were given a science inquiry problem test, a science process skills test, and a scientific concept test. The regression equation ($p<0.05$) was formulated with dependent variables, which are achievement on the science inquiry problem test and achievement on the science process skills test and the scientific concept test (by SPSS/PC$^+$10.1). An empirical method was used by applying each item with partial credit in ratio to the constant value of the independent variables of the regression equation formulated categorically as to the science process skills. Hence, regardless of a successor or a failure of the same science inquiry problem, the interpretation of the result can be different according to the applied measurement; a dichotomous credit measurement or a partial credit measurement.

Comparison between the Dichotomous Measurement and Partial Credit Measurement

This part attempts to determine the reliability and rationality of this research by comparing values of the reliability and discrimination, and difficulty of the raw data measured by the dichotomous method and the raw data measured by using the partial credit method where partial credit is applied in ratio to the constant value of the regression equation as per the science process skills category. Each sampling subject was selected by stratified sampling, 640 were for the dictotomous, and 128 were for the partial credit assessment.

RESEARCH RESULTS

Coding the Problem Solving Process

In order to establish a problem solving type classification system based on independent variables needed to solve science inquiry problems, the application degree of science process skills and related science concepts are categorized. And as a base, the problem solving processes used and stages are divided. Table 1 shows the coding system of classification of the science inquiry problem solving types.

The coding system in Table 1 was applied after the protocol was classified into phrases or clauses, which were collected from retrospective interviews and think-aloud method of the thinking process as sampled students solved 20 items in each science process skills category. There were six coders, and inter-rater reliability was 95%.

Analysis and Classification of the Science Inquiry Problem Solving Process Type

The protocols were made up of the data collected from the think-aloud method and retrospective interviews, and total 1,240 protocols (31 successors per item + 31 failures per item; total items are 20) were categorized by the coding system as shown in Table 1, and then their science inquiry problem solving processes were categorically analyzed as either successes or failures respectively.

In order to minimize the chance error due to subjective judgments, three experts in science education were participated in and the final conclusion was based on the results of their analysis. Inter-rater reliability among experts was 98%.

In classifying the problem solving types, PA-CA is the type that uses both science process skills and science concepts to the fullest in solving science inquiry problems, PA-CP is the type that applies the science process skills fully but applies the science concepts only partially in solving the problem, PA-CN is the type that applies the science process skills fully but uses the wrong science concepts in solving problems. PP-CA is the type that partially uses the science process skills and fully uses the science concepts in solving the problems, PP-CP is the type that uses both the science process skills and science concepts partially in solving problems, PP-CN is the type that uses the science process skills partially and uses the wrong science concepts in solving problems. PN-CA is the type that does not use the science process skills but uses the science concepts only in solving problems, PN-CP is the type that does not use the science process skills but uses partial science concepts in solving problems, and PN-CN is the type that uses both the science process skills and the science concepts incorrectly in solving problems. Therefore, PA-CA is the best problem solving type and the ultimate goal of education in improving science inquiry problem solving ability, and the PN-CN is the completely opposite.

According to the classification of the problem solving types in this study, there are sample students who succeeded or failed to solve problems regardless of examiners' intention. This suggests that we should use alternative assessment methods instead of the current dichotomous assessment method. The science inquiry problem solving types, classified by the results of this research, are shown in Table 2.

Formulation of Regression Equation of Science Process Skill Category

Six hundreds and forty high school students were provided with a science inquiry problem test, a science process skills test, and a scientific concept test. The achievement of the science inquiry problems is marked as Y, science process skills achievement as X, science

Table 1. The coding system of classification of the problem solving processes

Application of Process Skills and Science Concepts	Symbol
· Thinking process that used the science process skills with fully	··· PA
· Thinking process that used the science process skills with pattially	··· PP
· Thinking process that did not use the science process skills	··· PN
· Thinking process that applied all science concepts with correctly	··· CA
· Thinking process that applied science concepts with partially	··· CP
· Thinking process that applied wrong science concepts	··· CN

concept achievement as Z, the ability to recognize the problem and formulate a hypothesis among many science process skills is marked as $_a$, the ability to design and perform experiments as $_b$, the ability to interpret and analyze data as $_c$, and the ability to draw a conclusion and formulate a generalization as $_d$.

The regression equations, which were formulated by the dependent variables (the achievement degrees in the science inquiry problem measurement test by the four categories) and the independent variables (the science process skills measurement test and science concept measurement test), are as follows; $Y_a = 0.03 + 0.16X_a + 0.29Z_a$, $Y_b = -0.20 + 0.21X_b + 0.45Z_b$, $Y_c = -0.32 + 0.13X_c + 0.47Z_c$, $Y_d = 0.61 + 0.09X_d + 0.29Z_d$, $Y = -1.41 + 0.13X + 0.47Z$.

In particular, it was proved that science process skills play a crucial role in deciding a success or a failure in solving science inquiry problems from the category of designing and performing an experiment, while the science concepts play a crucial role in solving science inquiry problems from the category of interpreting and analysing an data.

Problem Solving Type and Application of Partial Credit

Science inquiry problem test items are divided into categories as shown in Table 3, each science process skills category has 5 items, making 20 items in total.

In reference to the ratio of partial credit as per application degree of science process skills and science concepts, the researcher gave 0.16:0.29 to items belonging to the category $_a$, 0.21:0.45 to category $_b$, 0.13:0.47 to category $_c$, and 0.09:0.29 to category $_d$.

Comparative Analysis of the Two Assessment Methods

The result of comparative analysis of the two assessment methods, which is based on the calculated reliability, discrimination, and difficulty of the raw data assessed by partial credit system and the raw data assessed by dichotomous system, is shown in Table 4.

The results suggest that in assessing the achievement of the same science inquiry problem, application of partial credit suitable for problem solving types classified by the thinking process in solving the problems is better than that of the dichotomous credit in increasing the reliability, discrimination, and difficulty of the assessment.

DISCUSSION

Since 1960s there had been many researches on developing tests and inquiry learning models to improve science process skills in science education. The assessment of the science process skills has been criticized as being applicable only to low level students or assessments of very limited elements such as basic inquiry skills or high order inquiry skills.

In the process of learning a certain topic in science, it is impossible to teach and learn science process skills and science concepts independently, and many previous studies have pointed out that students use both science process skills and science concepts together in solving science inquiry problems

Considering this point students' problem solving

Table 2. Problem solving types classified by the results of this study

Science process skills \ Scientific concepts		Full application	Partial application	No application
		PA	PP	PN
Full application	CA	PA-CA	PP-CA	PN-CA
Partial application	CP	PA-CP	PP-CP	PN-CP
Incorrect concepts	CN	PA-CN	PP-CN	PN-CN

Table 3. Science inquiry problem distribution according to categories

Category	a	b	c	d	sum
Item number	1, 5, 9, 13, 17	2, 6, 10, 14, 18	3, 7, 11, 15, 19	4, 8, 12, 16, 20	20

Table 4. Comparison between two assessment method

Need condition \ Assesment method	Reliability	Discrimination	Difficulty
Dichotomous assessment	0.78	0.43	0.41
Partial credit assessment	0.96	0.51	0.57

abilities are assessed by developing science inquiry problems that are solvable when both science process skills and science concepts are used together. Nevertheless, since item forms are still taking multiple choices and dichotomous assessment methods, there has been criticism that the current assessment method is not giving enough consideration to the thinking process used in the problem solving process.

In order to improve such an assessment method, there were many theoretical arguments in literature background, but the evidences by the experimental data were few.

According to this regression equation, the reliability index, discrimination index, and difficulty index of assessment method that apply partial credit to nine different problem solving types proved to be more effective than dichotomous assessment. This suggests that it is more reasonable and reliable to shift to the assessment method that applies partial credit to different problem solving types based on the analysis of the thinking process in problem solving process instead of the dichotomous. This is also significant in considering the constructivist-learning paradigm, which emphasizes the concept reconstruction of the students in the science learning process and the fact that the science learning assessment is part of the learning process.

In this respect, the result of this research indicates that it is a reliable assessment method that can assess the achievement of both the science process skills and science concepts. And it also makes up for the problem in the dichotomous assessment method, and sufficiently reflects the students' problem solving process.

CONCLUSION

The science inquiry problems used in this research were developed to be solvable only when the science process skills, which is the procedural knowledge, is applied together with the declarative knowledge such as the basic science concepts and principles.

The researcher created a protocol made from the audio-taped data of the thinking process for solving these problems in the form of thinking aloud and retrospective interviews. By analyzing this protocol, the researcher classified the thinking process into 9 different problem-solving types with procedural knowledge and declarative knowledge as criterion. There were 9 problem solving types; the first is applied both procedural and declarative knowledge fully and perfectly, the second and the third apply one fully and the other partially, the fourth applies two different types of knowledge partially, the fifth and the sixth apply only one of the two fully, the seventh and the eighth apply only one of the two partially, and the last that failed to apply both types of knowledge.

In order to find out how much the achievement of the science process skills and science concepts can influence the science inquiry problem, the researcher formulated the regression equation ($p<0.05$). Categorical achievement of the science process skills that are procedural knowledge (X_a, X_b, X_c, X_d, and X), and the achievement of the declarative knowledge(Z_a, Z_b, Z_c, Z_d, and Z) are put as independent variables, while the categorical achievement of the science process skills of the science inquiry problem (Y_a, Y_b, Y_c, Y_d, and Y) are put as dependent variables. As the result, the regression equations are as follows; $Y_a = 0.03+0.16X_a+0.29Z_a$, $Y_b = -0.20+0.21X_b+0.45Z_b$, $Y_c = -0.32+0.13X_c+0.47Z_c$, $Y_d = 0.61+0.09X_d + 0.29Z_d$, and $Y = -1.41+0.13X+0.47Z$.

This result supports that even in solving the same science inquiry problem, depending on the category of the science process skills, the interaction degrees between the procedural knowledge and the declarative knowledge turn out to be different, and in solving science inquiry problems that belong to the ability to design and perform an experiment, procedural knowledge proved to play the decisive role, while in solving science inquiry problems that belong to the ability to interpret and analyze data, the declarative knowledge plays the decisive role. This result confirms a previous study(Lawson, 1982).

Based on the analysis of the thinking process in solving problems, students with higher achievements in the dichotomous method might have lower achievement, and others with lower achievement might have higher achievements.

The reliability index Cronbach' α produced 0.96, discrimination index produced respectively 0.43 and 0.51, difficulty index respectively 0.41 and 0.57, when the same science inquiry problem was assessed in dichotomous method, while the reliability index Cronbach' α produced 0.78 when assessed focusing on the thinking process in solving problems.

This research result suggests that it is more reasonable and reliable to shift to the assessment method that applies partial credit to different problem solving types based on the analysis of the thinking process in problem solving process instead of the dichotomous. This is also significant in considering the constructivist-learning paradigm, which emphasizes the concept reconstruction of the students in the science learning process and the fact that the science learning assessment is part of the learning process.

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