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Children's Generating Hypotheses on the Pendulum Motion: Roles of Abductive Reasoning and Prior Knowledge

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진자운동에서 아동의 가설 생성: 귀추와 선지식의 역할

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요 약: 이 연구의 목적은 진자 과제에서 학생들의 가설 생성에 있어서 귀추적 추론 능력이 중요한 역할을 한다는 가설을 검증하고자 하는 것이다. 가설을 검증하기 위하여 5학년 학생들을 대상으로 하여 진자 운동에 대한 가설 생성 검사와 진자의 길이에 대한 선지식 검사를 실시하였다. 진자의 길이에 대해 선지식을 가지고 있는 많은 학생들이 그네 과제에 대한 가설 생성에 선지식을 적용하지 못하였다. 이러한 결과는 학생들이 가설 생성에 실패한 이유가 단지 선지식이 없어서가 아니라 오히려 귀추적 추론 능력이 부족한 것과 관련된다. 학생들이 성공적으로 가설 생성을 하기 위해서는 선지식 뿐만 아니라 귀추적 추론능력도 요구된다. 그러므로 이 연구는 가설 생성 과정에 있어서 선지식 이외에도 귀추적 추론 능력이 중요한 역할을 한다는 주장을 지지한다. 이 연구는 학생들의 가설 생성 능력을 계발하기 위해서는 과학 교육에서 과학적 선언적 지식 뿐만 아니라 귀추적 추론 능력에 대한 교육도 함께 제공되어야 함을 시사한다.

주요어: 지식 생성, 가설 생성, 진자 운동, 선지식, 귀추

Abstract: The purpose of the present study was to test the hypothesis that student's abductive reasoning skills play an important role in the generation of hypotheses on pendulum motion tasks. To test the hypothesis, a hypothesis-generating test on the pendulum motion and a prior knowledge test about the length of the pendulum motion were developed and administered to a sample of 5th grade children. A significant number of subjects who have the prior knowledge about the length of the pendulum motion failed to apply that prior knowledge to generate a hypothesis on a swing task. These results showed that students' failure in hypothesis-generating was related to their deficiency in abductive reasoning ability, rather than the simple lack of prior knowledge. Furthermore, children's successful generating hypothesis should be required their abductive reasoning skills as well as prior knowledge. Therefore, this study supports the notion that abductive reasoning ability beyond prior knowledge plays an important role in the process of hypothesis-generation. This study suggests that science education should provide teaching about abductive reasoning as well as scientific declarative knowledge for developing children's hypothesis-generating skills.

Keywords: knowledge generation, hypothesis generation, pendulum motion, prior knowledge, abductive reasoning

Introduction

Hypothesis is defined as a single proposition proposed as a possible explanation for the occurrence of some observed phenomena (Barnhart, 1953). Science educators know well that scientific reasoning involves generating as well as testing hypotheses. Specifically, hypothesis-generating has been regarded as one of core reasoning processes in creative thinking and scientific discovery (Klahr and Dunbar, 1988; Kuhn *et al.*, 1988; Kwon *et al.*, 2000; Lawson, 1995). However, teaching of science and sci-

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ence textbooks have heavily concentrated on procedures for testing hypotheses (e.g., designing experiment, manipulating and controlling variables, collecting data, measurement, analyzing data, and etc.) and largely ignore procedures for generating the hypotheses (Kwon *et al.*, 2000). This educational ignorance probably reflects the deficiency of teaching strategy.

A certain hypothesis may be generated in a moment. On the other hand, a complex, revolutionary hypothesis may take some time to form. Sometimes a reasoner leaps to a hypothesis almost as soon as he sees a problem while another reasoner needs a time to generate a hypothesis about the same problem. What is the principal difference between good and poor reasoners in generating hypotheses? Generally speaking, there are two factors to influence hypothesis-generation. One factor is the reasoner's prior knowledge which is a stored prior experience. The other is the reasoner's ability to pick up the stored knowledge (Lawson, 1995).

An important alternative of hypothesis-generating factor has existed that would explain the performance differences in terms of the presence or absence of declarative knowledge (as opposed to procedural knowledge) specific to the solving of each task (c.f., Anderson, 1995; Korthagen and Lagerwerf, 1995). Science instructors assume that their students' prior declarative knowledge plays a crucial role in their ability to acquire new concepts. This view regarding the importance of prior declarative knowledge has been largely believed in terms of Ausubel's theory of meaningful learning (Ausubel *et al.*, 1978; Novak and Musonda, 1991). In other words, according to this domain-specific prior knowledge hypothesis, if students have acquired the necessary declarative knowledge, they will successfully generate alternative hypotheses. Lacking that knowledge, however, they will fail. The acquisition of declarative knowledge is not only a necessary condition for hypothesis-generating, it is also sufficient. In this view, it means that our students should have only specific declarative knowledge about the period of pendulum motion for solving successfully a pendulum task.

Traditionally, two types of reasoning, induction and deduction, have been recognized in the logic of science. By means of induction one ascertains how often in the ordinary course of experience one phenomenon will be accompanied by another. No definite probability attaches to the inductive conclusion. By means of deduction one predicts the special results of the general course of things, and calculate how often they will occur in the long run. A definite probability always attaches to the deductive conclusion because the mode of inference is necessary. According to Hempel (1966), and Popper (1968), science proceeds by free formulation of a hypothesis from which empirical tests can be deduced or induced. However, a long line of discussions have shown that another type of scientific reasoning, called retroduction or abduction, in addition to induction and deduction has existed in scientific endeavor (Burk, 1946; Giere, 1997; Klahr, 2000; Kwon *et al.*, 2000; Lawson, 1995; Peirce, 1903). For example, a well-known American philosopher Charles S. Peirce recognized a distinctive type of scientific reasoning (called abduction in his terminology) in addition to the traditionally recognized induction and deduction, which is a necessary condition for successful performance of scientific task (Fisher, 2001).

Presumably, hypothesis-generation involves a reasoning procedure with exploring, combining, comparing, and selecting possible alternatives (Kwon *et al.*, 2000): First, the process of hypothesis-generating starts with identifying qualitative constructs of the current causal question and the previously 'experienced world' which may have a strong qualitative likeness with the current 'question world'. Second, the scientific reasoner explores and combines several 'explanations' of the previously experienced world. Third, the reasoner compares the combined several explanations and selects the most possible one based on the qualitative likeness between the current question world and the previously experi-

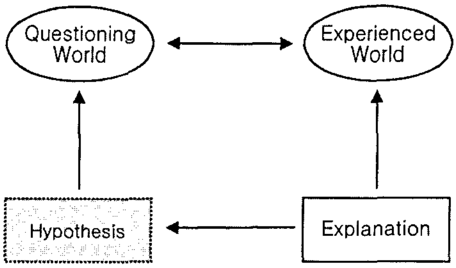


Fig. 1. The model of hypothesis-generating process.

Table 1. The predicted results of children's hypothesis generation by prior knowledge groups in the prior-knowledge hypothesis

Hypothesis	Prior-Knowledge Group		
	Angle	Length	Weight
Angle			
Length			
Weight			

ence world. Finally, the reasoner uses the selected explanation as the 'hypothesis' for the current question world. This process of hypothesis-generating is shown diagrammatically in Fig. 1.

A recent study has argued that in addition to the stored prior knowledge, the skills to represent the prior knowledge from his/her cognitive structure are presumably pivotal factors in hypothesis-generation (Jeong and Kwon, 2001). Therefore, the primary purpose of the present study in to test the notion that student's abductive reasoning skills exist in addition to prior knowledge as defined above. Furthermore, we test the hypothesis that one's abductive reasoning skills is required for her/his successful generation of hypotheses in pendulum motion tasks.

The Present Study

Pendulum motion has played a significant role not only in educational and psychological research but also in teaching children logical thinking since Jean Piaget's great works. Piaget and Inhelder, in their *The Growth of Logical Thinking from Childhood to Adolescence* (Inhelder and Piaget, 1958), describe the pendulum motion tasks that Piaget and Inhelder gave to children to ascertain the extent to which they could isolate and manipulate potential variables (length, amplitude, weight) that affected the period of pendulum motion. Performing the task of isolating and controlling the variables was considered as a window into child's logical ability and their developmental process. These tasks became common in the testing of logical thinking (Matthews, 2000).

The present study adapted the pendulum task as an experimental tool to investigate children's hypothesis-generating ability. The purpose of the present study is to test the hypothesis that children's abductive reasoning skills play an important role in the generation of scientific hypotheses on a pendulum task. To test the hypothesis, a hypothesis-generating test using a swing as a pendulum motion task and a prior-knowledge test about the period of simple pendulum motion were administered to children at 5th grade.

By the types of their prior knowledge, children are divided into three groups, namely, angle, length, and weight prior-knowledge. According to the prior knowledge hypothesis, if children have the prior knowledge about potential variables that affect the period of pendulum motion, they all should generate hypotheses on the swing task, which are related to the variable that they already have believed to affect the pendulum motion. The predicted result patterns of the prior knowledge hypothesis are shown as Table 1 and prediction 1 of Fig. 2.

An alternative explanation is related to abductive reasoning skills. In this view, children's successful performance on the swing task is affected by their abductive reasoning skills, rather than just their prior knowledge about potential variables which affect pendulum motion. Therefore, the predictions of this alternative is that children's hypotheses on the swing task are not related only to their prior knowledge of potential variables, such as angle, length, and weight. Rather, their hypotheses on the swing tasks will be randomly distributed to one of three hypoth-

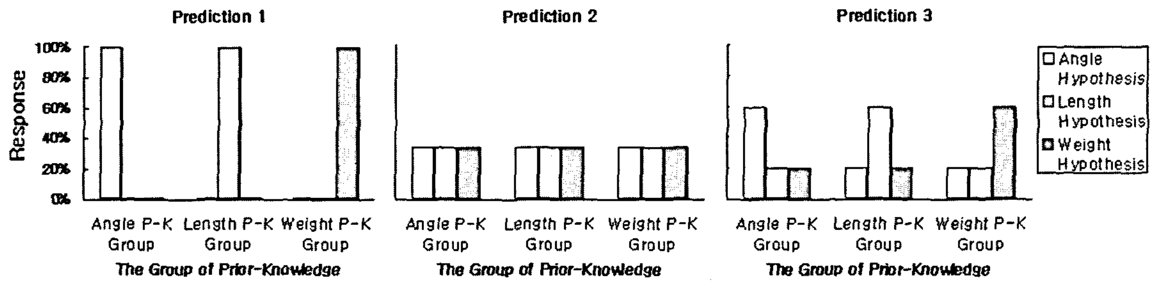


Fig. 2. The predicted results of alternatives of the prior knowledge, the abductive reasoning, and the combined.

eses regardless of prior knowledge of the pendulum motion. This prediction is shown in prediction 2 of Fig. 2.

The knowledge-abduction hypothesis is a combination of the above two hypotheses. The knowledge-abduction hypothesis leads to the prediction that children will generate all three type of hypotheses. However, the number of such responses will be different according to the type of prior knowledge. The number of the subjects who will respond to the hypothesis related to the potential variables to affect the pendulum motion is more than the number of other subject who will respond to other hypothesis. The predicted results of this hypothesis is shown in prediction 3 of Fig. 2.

Methods

Subjects and Procedures

A sample of 290 five graders (164 female, 126 male) was selected from four elementary schools in a Korean metropolitan area. The subjects were 9.9-12.1 years of age (mean age = 11.1 years, SD = 0.4). Two types of tests, a hypothesis-generating and a prior-knowledge test, were designed to investigate the subjects' hypotheses and prior-knowledge about pendulum motion. The hypothesis-generating test was administered to identify the children's hypotheses and to analyze the content categories of their hypotheses on a swing task. The prior-knowledge test was administered to reveal the children's prior-knowledge and to evaluate their prior-knowledge about the period of a simple pendulum motion. Furthermore, 124 children, who generated hypotheses with the internal factors of the simple pendulum and responded logically to the items 1 and 2 of the prior-knowledge test, were sampled again from the 290 subjects for the analysis of the hypothesis types by the prior knowledge group.

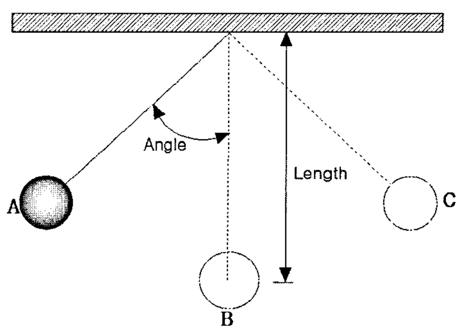
Instruments

The hypothesis-generating test: The hypothesis-generating test was designed to test hypothesis generation in a swing situation which phenomenon presumable relates to the simple pendulum motion. There were two swings moving at different speeds in the test. Children were asked to think and record what cause make a difference in the speed of the swings. The contents of the test are as follows:

> While Mary and Joe got on each swing, they detected that Joe's swing is faster than Mary's. So they decided to measure the speed of two swings. They didn't take any actions such as stamping their feet during the measuring. The measuring results are shown in following a Table.
>
> The periods of Mary's swing and Joe's swing
>
> | Swing | Period (Time for 10 swings) |
> |---|---|
> | Mary's | 32 |
> | Joe's | 25 |
>
> Why did Joe's swing go back-and-forth faster than Mary's? What caused the difference in the periods between Joe's swinging and the Mary's swinging?

The prior-knowledge test: The prior knowledge test is a multiple-choice test to investigate children's prior knowledge about pendulum motion. In the test, subjects were asked to respond to one of three variables which affect the period of the pendulum motion. The three variables are angle, length, and weight of a bob. Yang (2000) investigated children's prior knowledge about variables which determine the period of pendulum. The study showed that 33.1% of the fifth-graders responded to the angle (height) as the variable affecting the pendulum's period, while 26.0% and 7.4% of the fifth-graders responded to weight of a bob and length of suspension, respectively. Further, the others responded with a combination of these three variables. These result indicates that children's hypotheses on a pendulum task relate to the internal factors of the pendulum motion, such as angle, length, and weight. Therefore, this study used the three variable, angle, length, and weight as the factors affecting pendulum motion. The prior knowledge test is as follows:

Following picture shows an experimental setting of a simple pendulum.



1. In this experiment, the bob swings repetitively back-and-forth along the line from A through B to C and back again A. What factor increases or decreases the time of each swing?

a. angle b. length c. weight of bob d. I don't know

2. How can you make the pendulum move more quickly?

a. by decreasing the angle
b. by increasing the angle
c. by decreasing the length of the string
d. by increasing the length of the string
e. by decreasing the weight of the bob
f. by increasing the weight of the bob
g. I don't know

Results and Discussions

Children's Hypotheses

Children's hypotheses generated in the hypothesis-generating test are reported in Table 2.

As shown in Table 2, the categories of children's hypotheses were classified into three types. The first type (1-11 in Table 2) involves internal factors of a simple pendulum. In this type, 1-3 hypotheses are related to the angle of a pendulum, 4-6 are related to the length of a pendulum, and 7-11 are related to the weight of a bob. The second type (12-22) involves external factors, such as skill, exercise, and wind. Hypotheses 23-25 are classified as a non-scientific-hypotheses. The 23rd is just the repetition of the question while the 24th and 25th far from a an answer to the hypothesis-generating question.

Children's Prior Knowledge

The responses to children's prior-knowledge questions are summarized in Table 3.

As shown in Table 3, 203 subjects among 290 responded consistently across the items 1 and 2, which is presumably logical response to the prior-knowledge test. However, 75 subjects responded inconsistently across the items 1 and 2. For example, 17 subjects responded that the weight of the bob determined the period of the pendulum motion to item 1. However, they responded that decreasing the angle reduced the period of the pendulum motion to item 2. Furthermore, 12 subjects responded to that they didn't know. These inconsistent responses presumably indicate their deficiency of the knowledge about the pendulum motion.

In addition, 203 subjects who responded consis-

Table 2. Children's hypotheses to the hypothesis-generating test

Content categories	Frequency
Internal factors	168
1. Joe's swing went up lower than Mary's.	18
2. The distance of back-and-forth motion of Joe's swing was shorter than Mary's.	8
3. Joe's swing went up higher than Mary's.	10
4. The ropes of the swings were different in length.	4
5. The length of the ropes of Joe's swing was shorter than Mary's.	18
6. The length of the ropes of Joe's swing was longer than Mary's.	8
7. Mary's weight and Joe's weight were not same.	6
8. Joe's weight was lighter than Mary's.	51
9. The weight of Joe's swing was lighter than Mary's.	6
10. Joe's weight was heavier than Mary's.	37
11. The weight of Joe's swing was heavier than Mary's.	2
External factors	90
12. Joe was able to get on a swing with specific skill.	17
13. Joe begun to get on a swing earlier than Mary did	15
14. Joe swung better than Mary did	12
15. Joe was stronger than Mary	10
16. Joe's swing was new.	9
17. Wind stud against the movement of Mary's swing	7
18. There was something wrong with Mary's swing	6
19. Joe took exercise better than Mary did	4
20. Joe had a fine physique.	4
21. Joe's swing was older than Mary's.	3
22. Joe's swing had little frictional resistance.	3
The others	32
23. Joe's swing was faster than Mary's.	15
24. Joe measured exactly the swing time.	3
25. The speed of the swings of are same.	2
26. I don't know.	12
Total	290

Table 3. Summary of responses to prior-knowledge questions

Item 2	Item 1			
	Angle	Length	Weight	I don't know
Decreasing Angle	46	4	17	
Increasing Angle	15		1	
Decreasing Length	13	42	13	4
Increasing Length	1	8	10	
Decreasing Weight	7	3	54	
Increasing Weight	4	2	38	
I don't know		1	2	5
Total	86	60	135	9

tently to items 1 and 2 of the prior-knowledge test were divided into three groups, such as group A (angle), group L (length), and group W (weight), by the response to the item 1. Furthermore, each group was divided into two subgroups by the response to the item 2. First, the group A (N=61) believed that the angle of the swing determines the period of the pendulum motion. In this group, subgroup DA (N = 46) believed that the decreasing of the angle decreases the period of the pendulum motion. On the contrary, subgroup IA (N = 15) thought that the increasing of the altitude decreases the period of the pendulum motion. Second, the group L (N = 50) believed that the length of the string determines the swing speed. In this group, subgroup DL (N = 42) claimed that the decreasing of the length of the string decreases the period of the pendulum motion. On the contrary, subgroup IL (N = 8) believed that the increasing of the length of the string decreases the period of the pendulum motion. Third, the group W (N = 92) claimed that the weight of the bob determines the swing speed of the pendulum. In this group, subgroup DW (N = 54) thought that the decreasing of the weight of the bob decreases the period of the pendulum motion. On the contrary, subgroup IW (N=38) believed that the increasing of the weight of the bob decreases the period of the pendulum motion.

Analysis of Hypothesis Type by Prior Knowledge

A sample of 124 children, who generated hypotheses with the internal factors of the simple pendulum and responded logically to the items 1 and 2 of the prior-knowledge test, was selected from the 290 subjects for the analysis. And their hypotheses were analyzed by the type of prior-knowledge.

As shown in Table 2, the children's hypotheses were classified into one of three types. Among the three types of hypotheses, the hypotheses of the first type involved internal factors of a pendulum, such as, angle, length, and weight. However, the second type involved external factors of the swings rather than internal factors of the pendulum. And the third type is not appropriate hypothesis for this task. Therefore, this study analyzed the hypotheses of the first type by prior-knowledge groups, that is angle, length, and weight of prior-knowledge groups, to test the roles of subjects' prior knowledge, abductive-reasoning and knowledge-abduction.

Table 4 shows frequencies of internal factor hypotheses generated by each prior-knowledge group. As shown, the percentages for the angle, length, and weight hypothesis were 35.3, 17.6, and 47.1% in the angle prior-knowledge group. In the length prior-knowledge group, the percentage of the angle, length, and weight hypotheses were 21.4, 50.0, and 28.6%, respectively. In addition, the percentage of the angle, length, and weight hypotheses were 17.7, 8.1, and 74.2%, respectively for the weight prior-knowledge group. A bar chart showing the percentage has be plotted as Fig. 3.

Table 4. The frequency of internal factor hypothesis by prior-knowledge group

Hypothesis	Prior-Knowledge Group		
	Angle	Length	Weight
Angle	12 (35.3)	6 (21.4)	11 (17.7)
Length	6 (17.6)	14 (50.0)	5 (8.1)
Weight	16 (47.1)	8 (28.6)	46 (74.2)
Total	34 (100)	28 (100)	62 (100)

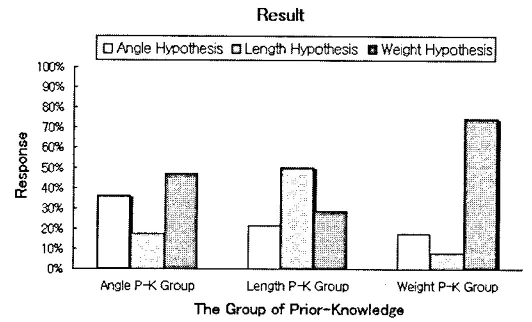


Fig. 3. Percentage of hypotheses by prior-knowledge groups.

Fig. 3 shows that the percentages of angle and weight hypotheses are higher than the percentage of length hypotheses in the angle prior-knowledge group. In the case of length prior-knowledge group, the percentage of length hypothesis is higher than any other. Also, in weight prior-knowledge group, the percentage of weight hypothesis highest. These results can be compared with the predicted results shown in Fig 2. According to the prior-knowledge alternative, children who have acquired the necessary declarative knowledge should successfully generate hypotheses related to their declarative knowledge. However, Fig. 3 reveals that many children did not employ their prior-knowledge of the pendulum motion to generate hypothesis for the swing task. Thus, these results do not conform to the expectations of the prior-knowledge alternative.

Fig. 3 results also do not match to prediction 2 of Fig. 2 that abductive reasoning alone is required for hypothesis generation.

However the combined prediction (3) in Fig. 2 fits more closely to the results of Fig. 3. Although the bar of angle hypothesis of the angle prior-knowledge group is not the highest percentage, the bars of length hypothesis of the length prior-knowledge and the weight hypothesis of the weight prior-knowledge groups are the highest percentage. In addition, the bar of angle hypothesis of the angle prior-knowledge group is shown higher than the bar of length hypothesis and close to the highest bar. Therefore, the results of the Fig. 3 provide a positive evidence to support the combined knowledge-abduction explanation in children's hypothesis-generating.

Cognitive psychologists also believe that the process of knowledge generation is the result of an interaction between declarative knowledge and procedural knowledge (Gagne *et al.*, 1993; Solso, 2001; Anderson, 1995). For example, a scientist might generate a hypothesis that is a proposition intended as a possible explanation for an observed phenomenon. The input information ("Why do male Dawson's bees to exist in two distinctly different size groups? I need to generate a hypothesis for the phenomenon.") would be transformed to produce an out put (the hypothesis: minor males are the incidental byproduct of external environmental factors) that looks quite different from the input. The previous example shows that procedural knowledge is used to operate to generate hypotheses, and knowledge (such as hypothesis) generation is the result of interaction between declarative knowledge for prior knowledge and procedural knowledge for abductive reasoning.

Conclusions and Educational Implications

The present results provide support for the hypothesis that student's abductive reasoning skills beyond typical sorts of prior or declarative knowledge exist and might be required for generating scientific hypotheses in pendulum motion tasks. This study shows that these skills have been used by students to generate hypotheses for the pendulum motion tasks. The evidence suggests that the presence of prior knowledge of pendulum motion alone is not sufficient to produce hypotheses. Hypothesis generating demands some representing skills, we call abductive reasoning skills, beyond possessing prior knowledge. This is not to say that prior knowledge is unimportant in generating hypotheses. Prior knowledge have been used as resources for generating hypothesis. Therefore, results of this study may tell us that knowledge-generation in science is completed by compensatory interaction between prior knowledge and scientific reasoning, such as abductive reasoning of this study, in cognitive structure.

Results of this study also showed that 14 of 28 subjects who believed that length affected the period of pendulum motion did not generate the length hypothesis. This result supports the notion that hypothesis-generating requires the reasoning skills to explore, select, and represent possible alternatives in explanations of the previously experienced situation. Clearly, this is an example of what we call abductive reasoning skills. Interestingly, the conclusion that a new cause to produce hypothesis-generating in pendulum motion task exists seems to have been foretold by Charles S. Peirce (Peirce Edition Project, 1998). Although Peirce's notion of retroductive reasoning was not widely recognized by science philosophers and educators, several studies have found that his notion of retroductive or abductive reasoning beyond inductive and deductive reasoning exists in scientific reasoning.

Student's abductive reasoning skills beyond prior or declarative knowledge exist and be required for generating scientific hypotheses. Therefore, school science teachers should concern with not only introducing declarative knowledge but also developing students' abductive reasoning ability in their classroom. To do this, a careful analysis and selection of various scientific issues and the development of those selected issues as educational materials should become matter of concern in science teaching. As Inhelder and Piaget (1958) developed its extensive usefulness for testing children's thinking process, the pendulum motion can be used as one of excellent educational materials for teaching and developing students hypothesis-generation skills as well improving their declarative knowledge related with the pendulum motion.

Acknowledgments

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