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Expert-novice differences of mental representation and problem solving strategy in mechanics problems

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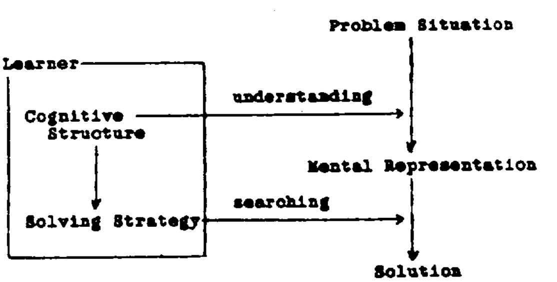
I. Introduction

A. Need for study

Problem Solving skill as high-order skill is one of the most important objectives in physics education. In order to achive this goal, teachers devise many hands-on instructional activities such as demonstrations, field experiences, and laboratory experiments. Recent empirical evidence, however, reports that current instructional practice does not facilitate the attainment of the identified goal.

From 1960s, cognitive psychologists using an information processing model have made much progress in understanding the human thinking process. When students encounter a problem situation, they make a mental representation by using their own cognitive structures and then try to find a solution from the representation by applying their problem solving strategies(See Fig. 1). Understanding processes generate a representation of the task including the givens, the goal, the underlying structure and any strategies. Search process is the transition between knowledge states in problem spaces(Lippert, 1987)



〈Fig. 1〉 Model of problem solving process

Because each student has his/her unique cognitive structure, the output, mental representation and problem solving process, may different from person to person.

In this study, patterns of mental representation and types of problem solving strategies will be investigated with students cognitive structure. From the findings of protocol analyses. some implications for the development of problem solving training will be drawn.

Research questions of this study follow:

(1) How do learners represent physics problems and use their problem solving strategies ?

(2) How are representation style and problem solving strategy related to problem solving result ?

B. Limitations

Analysis of thinking-aloud protocol and interview are major methods of collecting the data of the response variables in this study. Basically an indirect method like this cannot detect the rapid cognition or tip of thinking.

This study covers only mechanics problems. When dealing with other content areas beyond this. there will certainly be some limitations which apply to the results of this study.

C. Definition of terms

(1) Mental representation is the image that the subject uses to represent their understanding of the problem.

There are four stages of representation based on Larkin (1981) as follow:

a) literal representation: just simple statement of the problem as it might be presented.

b) naive representation: sketch of the real-world situation.(eg. hammer. inclined slope)

c) physical representation: reflecting the physical concepts (eg. energy loss by friction. initial velocity = 0)

d) algebraic representation: equations are produced.

and then go to the algebraic stage.

In this study, a student's representation stage is classified from diagram drawing and/or the transcript.

(2) Cognitive Structure is a modifiable information structure that represents generic concepts stored in memory.

In this study, reasoning level based on formal operations (Lawson, 1978) is used as the cognitive structure variable.

(3) Problem solving strategy refers to the method used to search for a solution through the physics principles and laws based on the mental representations.

a) Means-ends strategy begins with the desired quantity and looks for equations including that quantity. Then it works backward, making as desired any unbound quantity needed to solve such an equation.

b) Knowledge-development (forward chaining) begins with the known quantities in the problem statement and applies appropriate equations to derive new quantities until the desired quantity is reached.

c) Random strategy looks for discretionary equations or uses equations arbitrarily. As student using this strategy does not have any consistant plan but just hopes to find some clues to arrive at the goal.

(4) Strategy presetting means that student decide their problem solving strategies before the actual solving process. In this study, whether the strategy is preset or not is determined by checking student's transcript.

(5) Coherency of strategy means that a student tries to solve the problem by using one route which he/she originally selects, not by using some equations here and there.

(6) Goal checking means the number of explicit readings of the problem goal during the problem-solving period.

(7) Final checking refers to the student's recheck of the solving process after solving the problem.

(8) Solving time is a duration of time from starting the problem to it's finish. The unit is seconds.

D. Main hypotheses

(1) Expert students will make different mental representations than novice students.

(2) Expert students will use different problem solving strategies compared to novice students.

(3) Problem solving process will different by the reasoning level test scores.

Ⅱ. Review of the literature

(1) Mental representation

Main focus of many studies has been in naive and physical representations. These two representation styles have some characteristics as shown by Table 1.

〈Table 1〉 Comparision between naive and physical representation

	naive	physical
entity	familiar	physical
inferencing	simulation	constraint
relation to principle	distant from it	closely tied to it
structure	tree	graph
inference source	single	redundant
entity property	diffused	localized

Chi et al.(1981) pointed out that there is big difference, at the naive and physical stages, between expert and novice. Generally a novice solver skips the third stage, trying to jump directly from a sketch of the situation to a set of equations. However, expert uses the rich physical representation to guide his/her problem solving.

Larkin et al.(1980b) and Larkin(1983) suggested that there were two kinds of representation styles in mechanics problem solving. Firstly, subjects understood that the given problem is structuralized by forces or kinematics principles. So the concepts such as force, acceleration, time, and distance are used to understand the problem. This style was named as Force–Kinematics(F–K) representation.

On the other hand, some students used kinetic energy, potential energy, and work for their problems. This style was named as Work–Energy(W–E) representation.

(2) Cognitive structure

Cognitive structure is a prototype in memory of frequently experienced situations that individuals use to interpret instances of related knowledge(Rumelhart, 1981).

Many psychological constructs might be the components of the cognitive structure to solve the mechanics problem, for example, prior knowledge about mechanics, mathmatical skill, misconception, cognitive development level(Champagne et al., 1980), and processing capacity.

In the correlation study with Afro–American students, Alick and Atwater(1987) reported that no correlation exists between cognitive development and problem solving strategies. The success of the student was found to be dependent on the choice of strategy in some instances and not in others. In some instances, cognitive development was found to be significant in the students' odds of success. They concluded that cognitive development, the choice of a strategy, and success are interrelated.

(3) Problem solving strategy

In the research about making simulation models for mechanics problems, Larkin et al. (1980b) implemented two strategies, means–ends analysis and knowledge–development. They reported that the means–ends model is used by many novice solvers while the experts often use the knowledge–development model.

Ⅲ. Method and procedures

A. Subjects

The subjects who originally participated in this study were graduate students(3), high school students(5), and college freshmen(4). They were classified into 2 groups, expert and novice.

The graduate students, experts, were enrolled in a doctorallevel physics course at The Ohio State University. All three had the experiences of teaching introductory college level physics.

The high school subjects were 12th graders in a suburban area of Columbus, Ohio. All 5 students had studied high school level physies. They had completed study of kinematics, force, energy and work principles. But 3 of them could not finish. In other words, they could neither attack to the problem nor remember some related formulae within the 30 minute time limit and gave up to solve anymore. Their data were discarded from analyses. The four college freshmen had finished college level physics which dealt with kinematics, force, energy, and work principles.

Therefore final sample consistd of 9 including 3 experts and 6 novices which are 2 high-school students and 4 college freshmen.

B. Instrumentation

(1) Mechanics Problem Test (Appendix A)

The Mechanics Problem Test had two parts, the practice and the main parts. Before entering the main problems, some practice problems were given. Those problems have the same format as the main problems with different content. The purpose of this part was to familiarize all subjects with the thinkaloud method.

Three main problems were selected from PSSC Physics (Haber-Schaim et al., 1986) and the article of Larkin(1983). They all dealt with the concepts of motion with friction and energy conservation.

The operations of multiple principles of either energy and work or forces were needed to solve the problems. This test took from 20-40 minutes.

(2) Reasoning Level Test(RLT)

Lawson's classroom test of formal operations(Lawson, 1978;Wiseman, 1981) was used for this study. This test contained 15 questions which require the conservation reasoning, proportional reasoning, control of variables, combinatorial reasoning, and probabilities.

To diminish the shortcomings of the classroom multiple choice test, demonstrations by investigator preceded the answer writing and students were required to write out their reasons for making that choice.

The questions on this test were solvable within about 40 minutes and the reliablity coefficient had been reported as .62 to .86(Lawson, 1978; Park, 1982)

C. Procedures

Each subject in this experiment had worked individually with the experimenter. At first, he/she took the RLT, then the exercise problems were given to the subject.

After the subject was well prepared, the main part of the Mechanics Problems Test was given and asked to "think aloud as much as possible while working the problem." As soon as the subject started to solve the problems, an audio tape recorder was started. When the subject was keeping silent longer than 10 seconds, experimenter asked "speak out please." Actually there was no time limit but the solving time of each problem was recorded for reference data.

Additional interview after finishing all problems had focused on the unclear part of the protocols. This interview, a retrospective probing, would cover the shortcomings of the think-aloud method(Lester, 1982).

D. Statistical analyses

Most of data analyses were done qualitatively. After that, some statistical analyses were used to support the qualitative decisions and to test for group differences on the RLT scores.

SPSSX commands, CROSSTABS for Fisher's exact test, NPAR TESTS for Kruskal-Wallas 1-way ANOVA, and NPAR CORR to find the intercorrelations, were used in this statistical analyses. The significant level of .10 was selected because of the small number of subjects and the characteristics of this pilot study.

Ⅳ. Analysis and result

A. Preliminary data analyses

(1) Reasoning Level Test

Only when both answer and reason were correct, the question was counted correct. The possible maximum score of this test was 15 by counting 1 point per one question. Subscores were computed for 5 scales:conservation concept, proportional reasoning, controlling variables, combinatorial reasonings, and probabilites. The data are shown at Table 2.

The results for each subject were compared with the protocol analyses.

〈Table 2〉 Reasoning Level Test score

subscale	N1	N2	N3	N4	N5	N6	E1	E2	E3
conservation	2	2	1	0	2	2	2	2	2
proportion	4	4	3	4	3	4	4	4	4
control var.	4	4	4	3	4	4	4	4	4
combination	1	2	1	2	2	2	2	2	2
probability	3	3	3	3	3	3	3	3	3
total	14	15	12	12	14	15	15	16	15

(2) Think—aloud protocols

The initial transcribed protocols were simple lists from the taped transcript. These included statements of principles, algebraic combinations, and statements of values.

From this list the statements reflecting processes of interest were selected. First, the sequence of problem representations from student's statements about the understanding of the problem were identified. Secondarily a sequential list of each physics principle mentioned or implied in a protocol was constructed. The problem solving strategy was charaterized and classified from the order of principles applied by each subject.

Then the result of each problem was checked and scored. The possible maximum score of each problem was two. In minor error cases such as algebraic error, one point was given. Others were given 0.

〈Table 3〉 Original data set from transcript

a) problem #1

	N1	N2	N3	N4	N5	N6	E1	E2	E3
diagram	1	1	2	1	1	1	1	2	2
repre. style	1	1	1	1	1	2	1	1	1
preset strategy	1	1	2	1	1	2	2	1	2
coherency	2	1	2	1	0	2	2	2	2
strategy	3	3	2	2	1	3	3	3	3
# of goal check	2	2	2	2	2	0	1	1	1
final checking	1	0	0	0	0	0	0	1	1
result	0	2	1	0	0	2	1	1	1

b) problem #2

	N1	N2	N3	N4	N5	N6	E1	E2	E3
diagram	2	2	3	3	2	3	3	3	2
repre. style	1	1	1	1	1	2	2	2	1
preset strategy	1	1	1	1	1	1	2	2	1
coherency	1	0	2	1	2	2	2	2	1
strategy	2	1	2	3	1	3	3	3	3
# of goal check	1	0	1	3	2	0	0	1	0
final checking	0	0	1	0	0	0	1	0	1
result	0	0	0	0	0	2	2	2	2

c) problem #3

	N1	N2	N3	N4	N5	N6	E1	E2	E3
diagram	2		2	3	1	1	1	3	2
repre. style	1		1	1	1	2	1	2	1
preset strategy	1		1	1	1	2	1	2	1
coherency	0		0	2	0	2	2	2	1
strategy	2		1	2	1	3	3	3	3
# of goal check	3		1	3	1	0	0	1	0
final checking	0		0	0	0	0	0	1	0
result	0		0	0	0	2	2	2	2

Diagram drawing: 1 'NO' 2 'NAIVE' 3 'PHYSICAL'
Representation style: 1 'FORCE-KINEMATICS' 2 'WORK-ENERGY
Presetting the strategy: 1 'NO' 2 'YES'
Cohenrency of the strategy: 0 'NO' 1 'LESS' 2 'YES'
Strategy: 1 'RANDOM' 2 MEANS-ENDS' 3 'KNOWLEDGE-DEVELOPMENT'
Final checking: 0 'NO' 1 'YES'
Result: 0 'WRONG' 1 'ALGEBRAIC ERROR' 2 'RIGHT'

Finally common errors of novice students were examined.

(3) Relationship of formal operations on representations and problem solving strategies

Based on the reasoning test and the kinetic problem test results, comparisions were made between the subject's errors and the subscores of the reasoning test. Kruskal–Wallas 1–way ANOVA were useful in analysing these differences.

B. Results

(1) Mental representation

As shown in Table 4, only two subject(N6 & E2) used the W–E representation and others including two experts represented the F–K style at the problem # 3. Three students(N6, E1, & E2) in the problem #2 used the W–E style. All students except one(N6) used the F–K representation at the problem #1.

〈Table 4〉 Representation styles and order of principles at problem #3

Force-Kinematics representation

	$v^2=v_0^2+2a(x-xo)$	$a=v/2l$	$F=pma$
N1	1	2	3
N3	2	3	1
N4	1	2	3
N5	1	2	
E1	3	2	1
E3	2		1

Work-Energy representation

	$Ei=(1/2)mv^2$	$Ef=0$	$W=pgl$
N6	1	2	3
E2	1	2	3

* Number represents the order in sequence.

All six novices used their representation style continuosly either F–K or W–E, however two experts, except one(E3), used both styles flexibly depending on each problem.

Generally in each problem, there was no significant group difference in the representation style between expert and novice by using Fisher's exact test.

However, the student's representation style was significantly different by the problem solving result score(See Table 5).

〈Table 5〉 Frequency of problem solving result score by representation style

problem	F-K 2	F-K 1	F-K 0	W-E 2	W-E 1	W-E 0
1	1	4	3	1	0	0
2	1	0	5	3	0	0
3	2	0	4	2	0	0

All subjects, whether experts or novices, who used the W–E style solved the problem correctly. Interestingly, the two high–school students did not use the W–E representation style.

(2) Diagram drawing

There was no significant difference of drawing diagram to understand the problem between expert and novice. Roughly there was a trend that the physical representation diagram was more used in problem #2 and less used in problem #1.

(3) Problem solving strategy

As shown in Table 4, subjects have applied the order of principles differently. In problem #1, six students (N1, N2, N6, E1, E2, & E3) were using the Knowledge–Development(KD) strategy while N3 and N4 were using the Means–Ends(ME) strategy and N5 used Random(RA) strategy. In problem #2, N1 and N3 applied the ME strategy and N2 and N5 applied the RA strategy. Then N1 and N4 applied the ME strategy and N3 and N5 applied the RA strategy to solve the problem #3.

By above analyses, the expert subjects used the KD strategy continuosly but novice used different strategies in different problems except one who kept using the RA strategy.

All subjects who got points for each problem, except in one case, used the KD strategy as shown in Table 6. However, all subjects who used the KD strategy did not necessarily get points. All subjects who used the RA method did not solve the problems.

〈Table 6〉 Frequency of score by solving strategy

problem	RA 0	RA 1	RA 2	ME 0	ME 1	ME 2	KD 0	KD 1	KD 2
1	1	0	0	1	1	0	1	3	1
2	2	0	0	2	0	0	1	0	4
3	2	0	0	2	0	0	0	0	4

(4) Reasoning Level Test(RLT) score

To search the difference of the Reasoning Level Test scores in each problem solving process, Kruskal–Wallas 1–way ANOVA was run. Table 7 shows the only significant processes at .10 level.

〈Table 7〉 Reasoning Level Test score differences by each problem

subscale	process	χ^2	p
conservation	staretegy of #1	7.675	.02
proportional	strategy of #1	5.429	.07
total	strategy of #1	6.333	.05
total	goal checking of #1	4.702	.10
total	representation of #2	2.939	.09
combination	strategy of #2	8.000	.02
control variables	goal checking of #2	8.000	.05
total	result of #2	4.702	.03
proportional	strategy of #3	7.000	.04
total	strategy of #3	6.222	.06
total	result of #3	4.702	.03

The conservation score and proportional score of the RLT were different by the kinds of problem solving strategy of problem #1. In other words, two students who missed the conservation tasks used the ME strategy and two students who have a weak proportional reasoning skill did not used the KD strategy in problem #1.

In addition, in problem #1, the lower total RLT scores they have, the less KD strategy they used, the more goal checling, and the more F–K representation style was used.

There was significant difference of combinatory reasoning score by the selection of solving strategy of Problem #2. All subjects who did not accomplish the combinatory problems used the ME strategy for problem #2. And students who had low score on the controlling variables subscale tended to have more goal checking in problem #2. Students who did not get a perfect score on the RLT failed to solve the problem #2.

There was a significant preference for solving strategy of problem #3 by proportional reasoners. Two subjects who did not fully show their proportional reasoning abilities used the RA strategy at problem #3. Students who did not get the perfect score at the RLT did not use the KD strategy and failed to solve problem #3.

Table 8 shows the Reasoning Level Test score differences in each problem solving process at overall three problems.

⟨Table 8⟩ Overall Reasoning Level Test score differences overall problems

subscale	process	χ^2	p
total	representation	8.880	.02
total	presetting strategy	3.852	.05
proportional	coherence of strategy	5.500	.06
conservation	strategy	8.101	.02
proportional	strategy	13.444	.001
combinatory	strategy	8.399	.02
total	strategy	14.756	.001
conservation	goal checking	6.861	.08
control variable	goal checking	10.870	.01
total	goal checking	12.357	.01
conservation	result	5.280	.07
proportional	result	5.139	.08
combinatory	result	5.139	.08
total	result	18.861	.000

Students who did not get a perfect score on the reasoning level test used the F–K style and might not have used presetting in their solving strategies.

The proportional reasoning scores were related to the coherency of solving strategy over all three problems. The lower the proportaional reasoning skill, the weaker the coherency of strategies. This may imply that mathematical skill is important to solve a physics problem.

Proportional reasonings and combinatorial reasoning scores were related to the selection of solving strategy. In other words, the smaller the two reasoning scores, the less often the KD strategy was used. And the higher score at the RLT, the more the KD strategy was used.

On goal checking, there was significant difference related to the conservation and controlling variables reasoning scores. The better the conservation or controlling variables subscale, the less goal checking during the problem solving. Students who got the lower scores at the conservation, proportional, or combinatory reasoning scale could not solve all three problems.

The lower score on the RLT, the more goal checking and the lower final result score.

(5) **Other supportive evidences**

Subjects who set their solving strategy prior to the solution of the problem did better than those who did not set a strategy. Experts who did not talk about solving strategy prior to attempting a solution may have set a strategy internally since there was a continuity of the solving process with the result.

By the overall correlation coefficient, the representation style was related to the diagram. The more W–E style was used, the more a physical diagram was drawn.

Goal checking was negatively related to the result. The Kendall correlation coefficient was −.53, −.56, and −.76 respectively and these were all significant at .05 level. This pattern may relate the ME solving strategy. The ME solvers tried to reduce the gap between the goal and the present state. Results show that the goal checking behavior was ineffective for solving these problems.

Expert subjects tend to use more final checking than novices but there was no significant difference between their results.

(6) **Common errors**

In problem #1, many subjects committed algebraic error including the three experts. Some students were confused between velocity and acceleration concepts. In problem #2, there were common errors to get the frictional force. They seemed not to familiar with the concept of frictional constant. Some subjects were assuming zero acceleration. In problem #3, there was the same error about frictional fotce as problem #2. There were some troubles about negative acceleration, that is decceleration.

V. Conclusion

A. Conclusions

The results of the data analysis support several conclusions. The generalizability of these conclusions is affected by the content area, the characteristics of the sample, the experimental setting, and instruments use for measurement.

1. Experts seemed to use different representation styles for different problems while novices used one representation style for all problems.

2. Representation style was related to the diagram pattern.

3. Experts used the KD Strategy continually while novice used various strategies.

4. It was hard to solve the problems by using the Means–Ends strategy.

5. The goal checking during solving the problem was negatively related to the results of the problems.

6. The variables which best predict the overall result were strategy, goal checking, and representation style.

7. There were some confusions between velocity and acceleration concepts. Students have little knowledge about frictional force.

B. Implications for instructional pratice

1. Some physics problems seem to be solved more easily by using the Force–Kinematics representation. Therefore, teachers should teach the best representation style for certain kinds of physics problem.

2. In multi–principle physics problems like the ones used in this study, the Means–Ends strategy is almost useless. Therefore, physics teachers should teach students to use the Knowledge–Development strategy with the presetting strategy and final checking. These are able to form an instructional model for physics problem solving.

3. The velocity and acceleration concept still remains as one of the most difficult in physics instruction. In addition to that, the frictional force concept was very unfamiliar to most subjects. These concepts are not strange but ordinary ones in a student's daily life. There can be many misconceptions about them. Therefore physics teachers should teach these concepts by using the conceptual change strategy using hands–on experience, before going to the abstract form.

C. Recommendations for further study

1. Experts used different representation style. What features of the problems affect the selection of representation style ?

2. Frequent goal checking is negatively related to the result. Is there any relation between the goal checking and processing capacity ? Or is the frequent goal checking due to the lack of prior knowledge ?

3. Some subscales of the Reasoning test were related to the solving strategy, goal checking, and result. Can the subscales classify the problem solving, process variables such as strategy, goal checking, or results? On the other words, is it possible that the subscales diagnose the students problem solving process?

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Appendix A

MECHANICS PROBLEM TEST

1. The Force of friction between two solids is always in the direction opposite to the velocity but to a good approximation independent of the magnitude of the velocity.

With this information, if a person strikes a nail with a 0.75 Kg hammer moving at 10 m/sec. driving the nail 1.5 cm farther into a piece of wood:

What was the average force opposing the motion of the nail ?

2. A body of mass m starts from rest down a plane of length l inclined at an angle θ with the horizontal. If the coefficient of friction is μ, what is the body's speed as it reaches the bottom of the plane ?

3. What is the minimum stopping distance for a car traveling along a flat horizontal road, with initial speed vo, if the coefficient of friction between tire and road is μ ?

요 약

물리 문제에 있어서 전문가−초보자 간의 내적표상과 해결방안의 차이

박윤배

The Ohio State University, Columbus

과학교육에서의 문제해결력의 강조는 그 긴 역사를 가지고 있으나, 인지 심리학에서의 정보처리 모형을 사용한 문제해결과정의 분석이 사용되면서 그 교수가능성이 높아지고 있다.

본 연구는 하나의 탐색연구로써 학습자들이 물리문제를 해결하려는 과정에서 그 문제를 자기나름으로 이해하여 만든 내적표상과 동원한 해결방안이 문제해결에 어떤 관련이 있는지를 알아내보려고 한다. 물리전공 박사과정 학생 3명을 전문가로, 고등학생 2명과 대학 1년생 4명, 모두 6명을 초보자로 삼아 역학내용을 다룬 세 문제를 소리내어 푸는 과정을 개인별로 녹음하여 그 문제해결과정들을 분석하였으며, 학생들의 사고수준을 알기위해 사고 수준검사가 실시 되었다. 주로 질적 분석을 사용했으나 그 결론을 뒷받침하기위해 비모수통계 방법이 사용되었다. (유의수준 .10)

밝혀진 결론은 다음과 같다.

1) 내적표상은 피험자와 문제에 따라 각각 달랐다. 초보자들은 모두 한가지 표상을 세 문제에 걸쳐 계속 사용한데 반해, 2명의 전문가는 문제에 따라 다른 표상을 사용하였다.

이러한 표상의 형태에 따라 문제해결결과가 달랐다. 즉, 일-에너지 표상형태를 사용한 피험자가 더 나은 결과를 얻는것으로 나타났다.

2) 문제해결방안에 있어서는 전문가들은 세문제에 걸쳐 계속하여 지식-개발 방안을 사용하였으나 초보자들은 문제에 따라 다른 방안들을 동원하였다. 지식-개발 방안을 사용한 경우가 다른 것들에 비해 더 나은 결과를 얻는 것으로 나타났다.

3) 사고 수준검사(하위검사 또는 전체)의 점수와 문제해결과정 변인들-특히 내적표상의 형태, 문제해결방안의 종류, 목표확인 그리고 문제 해결력-간에는 유의미한 관련이 있는 것으로 나타났다.

4) 그외 속도와 가속도 개념의 혼동, 마찰력 개념의 부정확 등이 공통적으로 범하는 실수였다.

본 연구가 과학교육 실제에 주는 함의로는 내적표상, 문제해결방안의 훈련을 통한 문제해결력의 향상을 들 수 있겠으며 이를 위한 세부연구가 실행되어야 할 것이다.