한국과학교육학회지 제22권 제2호. pp. 314~335 (2002)

Effects of Students' Prior Knowledge on Scientific Reasoning in Density

Yang, Il-Ho · Kwon, Yong-Ju · Kim, Young-Shin ·
Jang, Myoung-Duk · Jeong, Jin-Woo · Park, Kuk-Tae
(Korea National University of Education)

학생들의 사전 지식이 밀도과제의 과학적 추론에 미치는 영향

양일호 · 권용주 · 김영신 · 장명덕 · 정진우 · 박국태
(한국교원대학교)

ABSTRACT

The purpose of this study was to investigate the effects of students' prior knowledge on scientific reasoning process performing a task of controlling variables with computer simulation and to identify a number of problems that students encounter in scientific discovery. Subjects for this study included 60 Korean students: 27 fifth-grade students from an elementary school; 33 seventh-grade students from a middle school. The sinking objects task involving multivariable causal inference was used. The task was presented as computer simulation. The fifth and seventh-grade students participated individually. A subject was interviewed individually while the investigating a scientific reasoning task. Interviews were videotaped for subsequent analysis. The results of this study indicated that students' prior knowledge had a strong effect on students' experimental intent; the majority of participants focused largely on demonstrating their prior knowledge or their current hypothesis. In addition, studnets' theories that were part of one's prior knowledge had significant impact on formulating hypotheses, testing hypothesis, evaluating evidence, and revising hypothesis. This study suggested that students' performance was characterized by tendencies to generate uninformative experiments, to make conclusion based on inconclusive or insufficient evidence, to ignore, reject, or reinterpret data inconsistent with their prior knowledge, to focus on causal factors and ignore noncausal factors, to have difficulty disconfirming prior knowledge, to have confirmation bias and inference bias (anchoring bias).

Key words: prior knowledge, scientific reasoning, testing hypothesis, evaluating evidence

---

*received on 13 November 2001, 1st revised on 27 December 2001, accepted on 3 January 2002

I. Introduction

The most general goal of scientific investigation is to extend our knowledge of the world. Science is a term that has been used to describe both a body of knowledge and the processes that give rise to that knowledge. Science educators have been interested in children's understanding of both scientific concepts and scientific reasoning. Scientific reasoning broadly defined numerous procedural and conceptual activities such as asking questions, hypothesizing, designing experiments, using apparatus, observing, measuring, predicting, recording and interpreting data, evaluating evidence, performing statistical calculations, making inferences, and formulating theories or models (Keys, 1994; Lawson *et al.*, 2000; Gower, 1997; Schauble *et al.*, 1995). Because of this complexity, researchers traditionally have limited the scope of their investigations by concentrating on either the conceptual or the procedural aspects of scientific reasoning. That is, focus has been on the acquisition and development of two main types of knowledge, namely, domain-specific knowledge and domain-general strategies.

Although many science researchers studying the conceptual changes have described children's evolving prior knowledge within numerous domains, relatively little attention has been given to the mechanism by means of which prior knowledge is revised and new knowledge is thereby acquired. This distinction between concepts (domain-specific knowledge) and strategies (domain-general knowledge) is loosely mapped onto the distinction between declarative and procedural knowledge in the memory literature (Kuhn *et al.*, 1995).

Science educators and cognitive psychologists also have been interested in both the inductive processes involved in the generation of hypotheses and the deductive processes used in the testing of hypotheses. However, there seems to be considerable debate about the degree to which these processes are generalizable across domains of knowledge and experience. The research community appears to be divided into two groups according to how these process skills can be attained. One group favors a domain-specific approach (Alexander et al., 1994; Millar & Driver, 1987; Novak, 1984), while the other group supports a domain-general strategy (Linn, 1990; Niaz, 1992, 1994).

One approach to the reconciliation of domain-general structuralism and domain-specificity has been developed by Kuhn (Kuhn, 1989), who proposes that domain-general skills interact with domain-specific knowledge. In her investigation of the emergence of everyday and scientific reasoning strategies, she has shown that the skills exist at a level which transcends the specific content in which they were developed (Kuhn *et al.*, 1992). However, subjects' application of these new strategies varied with the specific content to which they were applied (Kuhn *et al.*, 1995). When people reason about real-world contexts, their prior knowledge is likely to impose strong theoretical biases. These biases may influence the initial choice of hypotheses in hypothesis space, and the strength with which they are held (Klayman & Ha, 1987; Schauble, 1991). Additionally, prior domain knowledge may influence the experimental strategies utilized to gather new evidence.

Klahr and Dunbar (1988) and Klahr et al. (1993) have used a similar approach to causal reasoning as Kuhn's conception of data-bound thinking, theory-based thinking, and coordination of theory and evidence (Kuhn *et al.*, 1995; Kuhn *et al.*, 1992). They consider scientific thinking to be problem solving which requires search in two distinct problem spaces: a space of experiments and a space of hypotheses. Their model of Scientific Discovery as Dual Search (SDDS) includes three processes: a) searching the hypothesis space to generate new hypotheses; b) searching the experiment space to evaluate hypotheses through experimentation; and c) evaluating evidence to compare the predictors derived from an hypothesis with the results obtained from the experiment.

Klahr *et al.* (1993) found that most sixth graders and some third graders understood that their task was to produce evidence to be used in support of an argument about an hypothesis, and were able to distinguish between theory (hypotheses) and evidence. Similar findings were reported by Sodian *et al.* (1991) who found that first- and second grade children were able to differentiate between hypothetical knowledge and evidence.

The purpose of this study is to identify characteristic problems that students encounter in scientific discovery, and classify them according to the main scientific reasoning. Specifically, the present study investigated causes of students' poor conducting of scientific discovery.

Ⅱ. Method

Subjects. The students participating in this study were 27 fifth-grade students from an elementary school in Pohang city and 33 seventh-grade students in a middle school in Kwangyang city. Both cities are industrialized city, and both schools are located in industrial complexes.

The participants were selected randomly by their teachers with approximately equal numbers for each gender. The participants' background was diverse. The teachers indicated that science experiments are major part of their regular classroom program. The task used in the present study had not been tried in the previous class hours.

Scientific reasoning task. The sinking objects task was used in this study, which is scientific reasoning task involving multivariate causal inferences. The sinking objects task was adapted from Penner and Klahr (1996). However, the task is presented on a microcomputer in the present study. The goal is to identify the factors affecting the rate of sinking in the water. Original materials in Penner and Klahr consisted of a set of objects and a pair of identical Plexiglas cylinders with 91 cm in height × 12 cm in diameter. During the experimentation phase, participants were asked to observe sinking rates by dropping objects in the cylinders which were filled with water to a height of 85 cm.

They are consisted of eight objects designed by changing the following three variables: shape (cube or sphere), size (large or small), and material (stainless steel or white Teflon). Table 1 lists the weight,

Table 1. Sinking time by shape, size, and material

	Sphere		Cube	
	Large	Small	Lage	Small
Steel	0.58 sec	0.62 sec	0.83 sec	0.91 sec
Teflon	1.23 sec	1.38 sec	1.71 sec	2.04 sec

volume, and mean sinking times of the eight objects. In here, sinking times are based on the means of 10 drops of each object conducted outside of the experimental context. Stainless steel and Teflon were chosen because they differ substantially in density (approximately 2.3 g/㎤ for Teflon and 8.0 g/㎤ for stainless steel).

The sinking objects simulation was presented in two phases that took approximately 20 minutes to complete. The first phase was to predict which object would sink faster in water. The second phase was to test their own hypothesis made in first the phase. In this phase the participants choose two objects in order to test their own theory, and then clicks the "Run" icon to show a display of experimental result. The participant returns to the control page by clicking simulation control icon to try new objects and to observe the results until he/she believes he/she has solved the current problem.

Research design and procedure. The fifth- and seventh-grade students participated individually in one 15 to 20 minutes problem session. The participants were interviewed individually by researchers while he/she was investigating a scientific reasoning task. The interviews consisted of four phases and videotaped for the later analysis.

Phase 1: Introduction and initial hypothesis

The investigation of the children's preexperiment knowledge was described here for the sinking objects task. Participants were asked to explain why things sink or float, and which object attributes are important for sinking fast in water.

Phase 2: Sinking prediction

Participants were introduced to the object set and familiarized with the list of object features. Participants were next presented with all 28 possible pairs of objects. For each pair, they were asked to predict which object would sink faster in water, and justify their answer. After this prediction, participants ordered the eight objects according to what they believed to be the fastest to slowest sinking.

Phase 3: Simulated experimentation

Participants were given an opportunity to test their prior knowledge. For each simulated experiment, participants chose one or two objects to drop. Before dropping the objects, participants were asked (a) what dropping the objects would tell them about sinking fast in water, that means that they were asked to generate a hypothesis, and (b) to predict which object would sink faster. The participants then dropped the object with computer simulation. Participants were asked to describe what happened, and what was important for sinking fast in water.

Participants were required to conduct a minimum of four experiments. Following their fourth experiment, they were asked, "Tell me about what is important for sinking quickly in water? What did you know from your experiment? How did you know that? Do you want to explore anything else?" If participants expressed uncertainty about the contributing factors to sinking speed, they were encouraged to conduct more experiments until they believe they have solved the current problem.

Phase 4: Consolidation and summary

Following the simulated experimentation phase, participants were asked to summarize their prior knowledge about relevant causal factors. If multiple attributes were mentioned, participants were asked whether or not the variables were of equal importance. Finally participants were also asked to describe what they thought the fastest possible sinking objects would be like.

Ⅲ. Results

Prior knowledge. The investigation of the participants' prior knowledge is described here for the sinking objects task. Participants were asked what makes a difference in the sinking speed before the computerized task is presented. Participants' prior knowledge about the attribute that determine sinking rates are listed Table 2.

The participants' reponses to the question about the prior knowledge were categorized into 11 response groups. The participant responses were presented in order from the most frequent response group down to the least frequent group based on the fifth-graders responses.

Table 2 shows that weight bias is the most frequent prior knowledge held by students. This response group 1 is stronger in the fifth grade (70.4%) than in the seventh grade (39.5%). A number of participants, and particularly the fifth-graders, revealed their prior knowledge by referring to the weight of objects as a causal factor.

Response group 2, which includes 11.1% of the fifth-graders and 6.1% of the seventh-graders, thought that being heavy and large material was important for sinking quickly. Response group 6 includes 27.3% of the seventh-graders who believed that being heavy and small material was important for sinking

Table 2. Participants' prior knowledge about the attribute that determine sinking rates of the objects (%)

Participants response group		5th-graders (n = 27)	7th-graders (n = 33)
1	Heavy	70.4	39.5
2	Heavy and Large	11.1	6.1
3	Heavy and sphere	7.4	3.0
4	Sphere	7.4	
5	Large and sphere	3.7	
6	Heavy and small		27.3
7	Small		12.1
8	Small and sphere		3.0
9	Heavy, small, and sphere		3.0
10	Light		3.0
11	Large		3.0
Total		100	100

quickly. Especially response group 7, containing of 12.1% of the seventh-graders, believed that the small objects sink faster and the weight of object is not causal variable.

Response group 3, which includes 7.4% of the fifth-graders and 3.0% of the seventh-graders, thought that the heavy and spherical objects sink faster and the object volume is not causal variable. Response group 5 and group 8 considered volume and shapes of objects as a causal factor. Response group 5, which includes 3.7% of the fifth-graders, revealed that large and spherical objects sink faster and the object volume is not causal variable. Response group 8 includes 3.0%of the seventh-graders who thought that small and spherical objects sink faster.

Response group 4, containing of 7.4% of the fifth-graders, believed that the spherical objects sink faster and the volume and weight of object are not causal variables. Response group 9, which includes 3.0% of the seventh-graders, revealed that all of three variables are important for sinking quickly. This group thought that the heavy, small, and spherical objects sink faster than the others. Response group 11 includes 3.0%of the seventh-graders who believed that large objects sink faster. They did not consider weight and shapes as causal factors.

To explore the participants' reasoning with regard to these prior knowledge, the participants were asked to explain their thinking. The majority of participants' explanation showed as follows:

E01 (male, 5th-grader): Having a small cross-sectional area dwindles the water resistance.

M11 (male, 7th-grader): A few years ago, I made various clay objects such as sphere, cube, and then drop them in water. I observed the sphere clay sinks faster.

E13 (female, 5th-grader): Because the heavier object pushes down, so it can't float.

E21 (female, 5th-grader): Because spherical object allowed it to slide through the water easier.

M10 (male, 7th-grader): Small object made it easier to go through the water.

M5 (male, 7th-grader): Heavy and spherical object sinks faster because it doesn't get trapped underneath.

E18 (male, 5th-grader): The heavier objects' speed increases because of the gravity.

E20 (female, 5th-grader): The heavier objects overcomes the water resistance.

In the participants' explanation of the own prior knowledge, major feature of the answers was that they revealed weight bias. Another major feature was they often used term of "water resistance".

Stability of prior knowledge. The investigation of the children's initial hypothesis is described here. In order to assess the stability of prior knowledge about sinking objects task, particularly weight bias, the prediction which is children's responses to the pairwise comparisons were analyzed. The consistency with which participants applied their knowledge prior to experimentation was assessed by computing the proportion of their pairwise comparisons that were consistent with the implicit pairwise comparisons derived from the rank-ordering task in interview phase 2.

63.0% of the fifth-graders changed their own prior knowledge, while remaining 37.0% of the fifth-graders were consistent with their own prior knowledge. In contrast, 42.4% of the seventh-graders changed their own prior knowledge, while 57.6% of the seventh-graders were consistent with their own prior knowledge. The differences between the grades and the consistence with prior knowledge were not statistically significant ($\chi^2 = 2.51$, $p > 0.05$).

Experimental rationale. Each experiment was coded with respect to not only the participant's explicitly stated intent, but also the intent suggested by three or more of their trials. If students begin experimentation with an prediction-oriented intent, this should be reflected in engineering stance (Schauble *et al.*, 1991) rather than science stance, to their first experimentation. The main objective of prediction-oriented practice is to optimize a desired outcome. In contrast, Hypothesis-oriented practice (science model) refer to the search for relations among variables.

In sinking objects task, 21.2% of seventh-graders were classified as a hypothesis- oriented, while remaining all of the fifth-graders and 78.8% of the seventh-graders were classified as a prediction-oriented. The differences between the grades and the experimental intents were statistically significant ($\chi^2 = 6.48$, $p < 0.05$).

Number of trials. To test differences in the number of trials for each grade, t-test was conducted. Table 3 shows that the differences between the fifth- and the seventh-graders' number of trials on sinking objects task were not statistically significant ($p > 0.05$). Although there was no significant difference in the trials number between the fifth- and the seventh-graders, the trials number of the seventh-graders ($M = 6.93$, $SD = 3.51$) was lower than the fifth-graders ($M = 7.82$, $SD = 6.23$).

Controling variables. In sinking object task, the independent variables are consisted of material, size, and shape. If participants understood the relationships between the question and the independent and dependent variables, then the task of identifying these variables consisted of finding the cause and the response in the causal question and classifying them as the independent variable and the dependent variable.

The present study views controlling variables as two types of generating instance strategies which require rule induction: maintaining noncausal variable strategy (MN), desultory and rule inductive strategy (DR). MN strategy is that the variables which are believed to be noncausal, are kept constant, while the remaining variables are manipulated in order to rule induction. DR strategy is randomly generating the instances in order to determine how to make a desired instance occur.

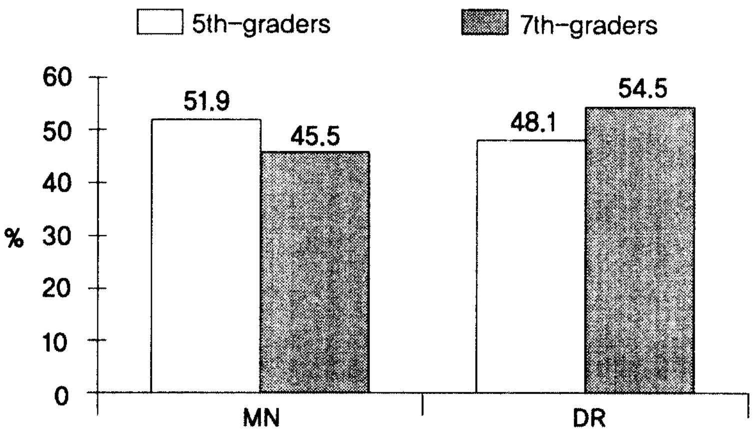
Fig. 1 shows that 51.9% of the fifth-graders and 45.5% of the seventh-graders used MN strategy, remaining 48.1% of the fifth-graders and 54.5% of the seventh-graders used DR strategy.

Confirming final conclusion. The confirming final conclusion means the degree of confirming or disconfirming experimental support that participants received for their final conclusions. The degree to which participants' final conclusions are supported by experimental evidence is a reflection of their understanding of the need to attend to all the evidence they generated.

In this study the majority of both grade participants' conclusions (66.7% of 5th-graders, 75.8% of 7th-

Table 3. t-test analysis of number of trials

	N	Mean	SD	t-value	p
5th-graders	27	6.93	3.51	0.70	0.49
7th-graders	33	7.82	6.23		



MN: maintaining noncausal variable strategy, DR: desultory and rule inductive strategy

Fig. 1. Comparison of generating instancestrategies

graders) were not supported by confirmatory outcomes. However younger grade participants had more confirming conclusions supported by confirmatory instances than older participants. Pearson Chi-square analysis indicated no significant relationship between the grades and the experimental support.

Prior knowledge and scientific reasoning. The investigation of the students' prior knowledge that affect the initial hypothesis, interpreting data, final conclusion is described here. It is shown in Fig. 2 that flow chart comparison of the percentage of how does the prior knowledge affect scientific reasoning.

In the hypothesis space of Fig. 2, students must explore potential explanatory hypotheses that vary in their plausibility and consistency, that is, a search space consisting of all rules possibly describing the phenomena that can be observed within a domain. Experiment space consists of experiments that can be performed with the domain and the outcomes of these experiments. In the experiment space, students must design experiments that will be informative in ruling out potential hypotheses.

The major feature of the Fig. 2 was that participants' initial hypotheses, two-third of the fifth- and seventh-graders, were affected by prior knowledge. Fig. 2 shows 25.9% of the fifth-graders' and 27.3% of the seventh-graders' initial hypotheses and final conclusions were affected by their prior knowledge. A path of H → Ib → C was not found. The patterns of scientific reasoning affecting by prior knowledge were similar to both fifth- and seventh-graders.

Case-study analysis. The purpose of the case-study analysis is to go beyond the quantitative analyses shown above in order to investigate participants' scientific reasoning. We provides qualitative analyses in the form of the detailed behavior of 6 participants, they were chosen to provide characteristics of the typical range of behavior across the grades.

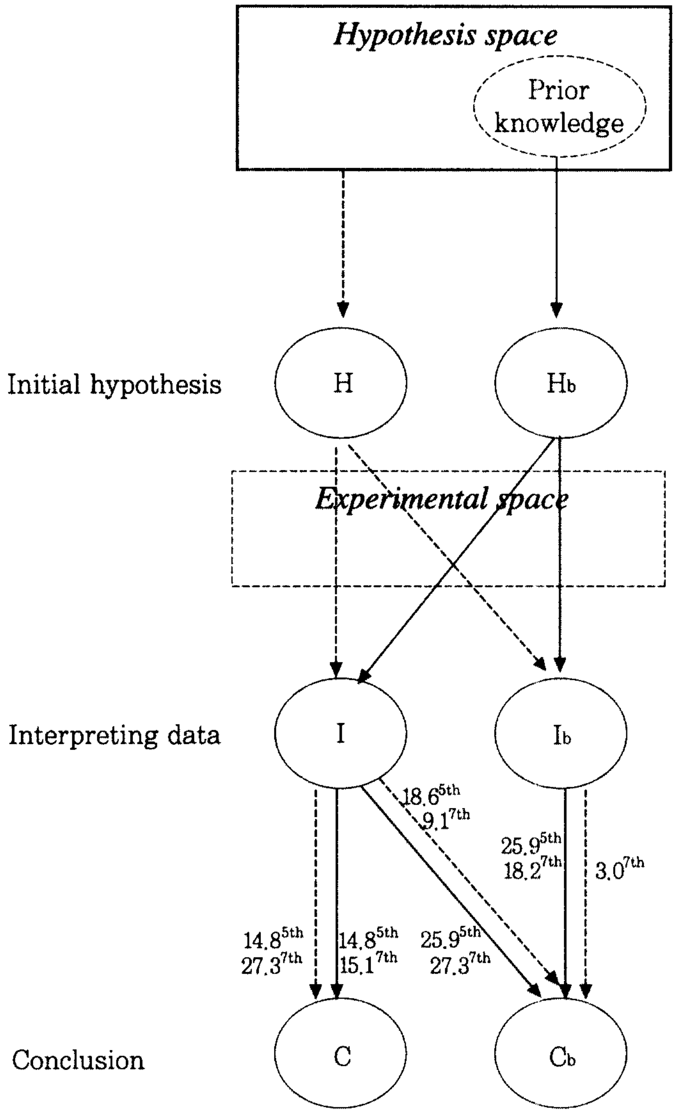


Fig. 2. Pattern of scientific reasoning affected by prior knowledge.

(1) Kim, K. I. (male, 5th-grader)

In the response to the prior knowledge phase, KKI stated that objects should be heavy and large in oder to sink quickly. KKI justified majority of his pairwise predictions solely on the basis of which object was heavier, none of his justifications referred to shape. He generated 4 instances in experiment phase. The sequence of experiments is shown in Table 4.

KKI chose the large steel sphere and large Teflon sphere for his first experiment. In response to the hypothesis probe, he stated that he was interested in seeing how object weight affected the sinking speed. When asked to predict the outcome, KKI stated that the heavier would sink faster, because of its weight. After watching the large steel sphere sink faster, KKI inferred that the heavier one sank faster.

For his second experiment, KKI again stated that he was interested in seeing how object weight affected the sinking rate. For this experiment, KKI selected the large steel cube and large Teflon cube, predicting that large steel cube would sink faster because it "weighs more." After watching the large steel cube sink faster, KKI stated that being heavier was important for sinking quickly.

For his third and final experiments, KKI again stated that he was interested in seeing how object weight affected the sinking rate. That is, KKI attempted to test how object weight affected the sinking rate. KKI concluded that weight was important for sinking faster.

This phenomenon, confirmation bias, that is a learner's tendency to seek information that confirms a hypothesis. KKI conducted only one potentially informative experiments for weight. KKI's generating instances, interpretation of experimental outcomes, and final conclusions reflect the effects of his prior knowledge. KKI selected values of variables that would demonstrate his hypothesis. That is, KKI adopted what Schauble et al. (1991) call an engineering, rather than a scientific, approach.

(2) Kim, S. I. (male, 5th-grader)

In the response to the prior knowledge phase, KSI stated that objects should be heavy in oder to sink quickly. KSI justified majority of his pairwise predictions solely on the basis of which object was heavier, none of his justifications referred to shape. KSI's prior knowledge was changed during pairwise predictions. After pairwise prediction phase, KSI thought that "the heavy and large one may go faster." KSI generated 7 instances in experiment phase. The sequence of experiments is shown in Table 5.

Table 4. KKI's sequence of experiments

	1st	2nd	3rd	4th
Selected objects	● : ○	■ : □	• : ∘	▪ : ▫

● = large steel sphere, ○ = large Teflon sphere, ■ = large steel cube,
□ = large Teflon cube, • = small steel sphere, ∘ = small Teflon sphere,
▪ = small steel cube, ▫ = small Teflon cube.

Table 5. KSI's sequence of experiments

	1st	2nd	3rd	4th	5th	6th	7th
Selected objects	●■	▪•	□○	▫∘	▪○	□●	▪□

● = large steel sphere, ○ = large Teflon sphere, ■ = large steel cube,
□ = large Teflon cube, • = small steel sphere, ∘ = small Teflon sphere,
▪ = small steel cube, ▫ = small Teflon cube.

KSI's prior knowledge in the primacy of weight motivated his first experiment, in which he chose to drop the large steel sphere and large steel cube. He replied to the hypothesis probe with a prediction: the heavy and large would sink faster. After seeing the heavy and large sink faster, KSI believed that being heavier and larger made it easier to "go through the water."

From his second through forth experiment, KSI again stated that he was interested in seeing how object weight and size affected the sinking rate. After observing the heavy and large sink faster, KSI stated that "I think my idea is correct." For his fifth experiment, KSI again tested that "the heavier and larger objects sink faster." In this experiment, KSI produced a surprising outcome contradicting his hypothesis. After seeing the light and small object sink faster, KSI conceived cognitive conflict. However, KSI had no an alternative hypothesis. KSI maintained the previous hypothesis on following experiments.

KSI chose the large steel sphere and large Teflon cube for his fifth experiment. After observing the large steel sphere sink faster, KSI inferred that "although object weighs more, larger object sink faster". For his final experiments KSI selected small steel cube and large Teflon cube. After observing the small steel cube sink faster, KSI inferred that "the heavier and smaller object sink faster".

KSI was asked to describe what he thought the fastest possible sinking objects would be like. KSI stated that being heavy and small were important for sinking quickly. However, in his fifth experiment, the lighter object sank faster. Also, five of his seven unique experiments, the larger object did sink faster. KSI's conclusion is based on a single experimental outcome. Particularly, KSI ignored the fifth experimental outcome.

(3) Kim, J. H. (male, 5th-grader)

In the response to the prior knowledge phase, KJH stated that objects should be heavy in oder to sink quickly. KJH's prior knowledge was not changed during pairwise predictions. KJH generated 8 instances in experiment phase. The sequence of experiments is shown in Table 6.

KJH's prior knowledge in the primacy of weight motivated his first experiment, in which he chose to drop the large steel sphere and large Teflon sphere. He replied to the hypothesis probe with a prediction: the heavy would sink faster. After seeing the heavy one sank faster, KJH believed that being heavier made it easier to "down in the water."

KJH's second experiment involved large steel cube and large Teflon sphere. As in his first experiment, KJH observed the heavy one sink faster. After observing, KJH stated that "I thought it would go faster if

Table 6. KJH's sequence of experiments

	1st	2nd	3rd	4th	5th	6th	7th	8th
Selected objects	● □	■ ○	▪ ○	▪ ○	▪ □	● •	■ •	▪ ●

● = large steel sphere, ○ = large Teflon sphere, ■ = large steel cube,
□ = large Teflon cube, • = small steel sphere, ◦ = small Teflon sphere,
▪ = small steel cube, ▫ = small Teflon cube.

it was heavier."

For his third and forth experiment, KJH chose small steel object and large Teflon sphere. Once again he answered the hypothesis probe with a prediction: the steel one will be faster because it is heavier. After observing the steel sink faster, KJH stated that "the steel object sink faster than Teflon ones." KJH investigated to compare all of steel objects with large Teflon sphere.

For his fifth experiment, KJH selected large Teflon cube and small steel cube. When asked to predict the outcome, he believed that the large Teflon cube would sink faster because it was heavy and large. After observing that the small steel cube sank faster, KJH inferred that the smaller sank faster.

KJH chose the large steel sphere and small steel sphere for his sixth experiment. In response to the hypothesis probe, he stated that he was interested in seeing how object size affected the sinking rate. When asked to predict the outcome, KJH stated that the smaller would sink faster. After watching both object sink same rate, KSI experienced cognitive conflict. KSI stated that "it sank slower because the small steel sphere weighs too less." KSI reinterpreted data in order to explain within his current theoretical framework without changing his current hypothesis.

For his final experiment, KJH selected the small steel cube and large steel sphere, he again stated that he was interested in seeing how object size affected the sinking rate. KJH predicted that the small would sink faster. This suggested that KJH believed size to be more important than weight. After observing the large sink faster, KJH inferred that "it sank slower because the volume of cube was too small." KJH concluded that "being appropriately small and made of steel was important for sinking quickly." As in sixth experiment, when KJH confronted negative results, he reinterpreted data in order to explain within his current theoretical framework without changing his current hypothesis.

(4) Shin, H. Y. (female, 7th-grader)

In the response to the prior knowledge phase, SHY stated that objects should be small in oder to sink quickly. SHY justified majority of her pairwise predictions solely on the basis of which object was smaller, none of his justifications referred to shape or weight. SHY generated 5 instances in experiment phase. The sequence of experiments is shown in Table 7.

SHY chose the small steel sphere and small Teflon sphere for his first experiment. In response to the hypothesis probe, he stated that he was interested in seeing how object size affected the sinking rate. When asked to predict the outcome, SHY stated that the heavier would sink faster, if both object had

Table 7. SHY's sequence of experiments on sinking objects task

	1st	2nd	3rd	4th	5th
Selected objects	• ◦	● •	▪ •	■ ●	■ □

● = large steel sphere, ○ = large Teflon sphere, ■ = large steel cube,
□ = large Teflon cube, • = small steel sphere, ◦ = small Teflon sphere,
▪ = small steel cube, ▫ = small Teflon cube.

same shape, because of its weight. After watching that the small steel sphere sank faster, SHY inferred that the heavier sank faster if shape was same.

For his second experiment, SHY again stated that he was interested in seeing how object size affected the sinking rate. For this experiment, SHY selected the large steel sphere and small steel sphere, predicting that small steel sphere would sink faster. After watching both object sink same rate, SHY stated that weight was not important for sinking speed.

For her third and forth experiments, SHY again stated that he was interested in seeing how object shape affected the sinking rate. After forth experiment, SHY stated that "I have no idea." Compare third and forth experimental outcomes with previous one, SHY experienced cognitive conflict.

For SHY's final experiment, she selected the largel steel cube and large Teflon cube, he again stated that he was interested in seeing how object weight affected the sinking rate. SHY predicted that the steel would sink faster. This suggested that SHY believed weight to be more important than size. After observing the heavy sink faster, she inferred that "if the shape is same, it would sink at the same. When the shape is difference, the heavier sink faster." SHY concluded that "being heavier object was important for swing quickly. The object size is not a causal."

However, SHY's conclusion was not supported by confirmatory outcomes. In SHY's second experiment, she stated that "the weight is not a causal." That is, SHY's conclusion conflict with previous experimental outcome. However, SHY ignored the second experimental outcome.

(5) Kim, Y. M. (female, 7th-grader)

KYM's prior knowledge is that "the lighter and smaller one swing faster". KYM generated 4 instances. The sequence of experiments is shown in Table 8.

Although KYM's prior knowledge was that weight and size were important for sinking quickly, she changed her prior knowledge into "heavy and sphere sink faster" during pariwise predictions. KYM chose large steel sphere and large Teflon sphere for her initial experiment. KYM predicted that the heavy would sink faster.

For KYM's second experiment, she selected large steel sphere and small Teflon sphere. As in her first experiment, she predicted that "the large steel sphere would sink faster because of its heavier and larger." After seeing large steel sphere sink faster, KYM had confidence that the weight made a different sinking rate.

Table 8. KYM's sequence of experiments on sinking objects task

	1st	2nd	3rd	4th
Selected objects	• ◦	● ◦	■ ▫	■ ○

● = large steel sphere, ○ = large Teflon sphere, ■ = large steel cube,
□ = large Teflon cube, • = small steel sphere, ◦ = small Teflon sphere,
▪ = small steel cube, ▫ = small Teflon cube.

KYM's third experiment involved the large steel cube and small Teflon cube. In response to the hypothesis probe, KYM stated that she was interested in seeing how object's weight affected the sinking speed if the shape was the same. When asked to predict the outcome, KYM stated that the heavier would sink faster, because of its weight. After watching the large steel cube sink faster, KYM inferred that the heavier sank faster if the shape was the same.

For KYM's final experiment, she selected large steel cube and large Teflon sphere. In response to the hypothesis probe, KYM stated that she wanted to know how object weight affected the sinking rate if the shape was not the same. When asked to predict the outcome, KYM stated that the heavier would sink faster, because of its weight. After watching the large steel cube sink faster, KYM inferred that the heavier sank faster although the shape was different.

KYM concluded that both being smaller and heavier are important for sinking quickly. However, in sequence of her experiments, KYM only varied on weight. That is, KYM confirmed only one thing that the heavier sink faster in her conclusion. There is no evidence that the smaller sink faster in her experiments.

(6) Nah, Y. S. (male, 7th-grader)

In the prior knowledge phase, NYS believed that objects should be heavy and small in oder to sink quickly. NYS's prior knowledge was not changed during pairwise predictions. NYS generated 5 instances. The sequence of experiments is shown in Table 9.

NYS selected the small steel sphere and large Teflon sphere for his first experiment. In response to the hypothesis probe, he stated that he was interested in seeing how object size affected the sinking speed. When asked to predict the outcome, NYS stated that the smaller would sink faster. After observing the small steel sphere sink faster, NYS inferred that the smaller sank faster.

For his second experiment, NYS stated that he was interested in seeing how object's weight affected the sinking speed when both objects' size were the same. For this experiment, NYS selected the large steel sphere and large Teflon sphere, predicting that large steel sphere would sink faster because it "weighs more." After watching the large steel sphere sink faster, NYS stated that being heavier was important for sinking quickly.

NYS's third experiment involved the large steel sphere and small Teflon cube. In response to the hypothesis probe, NYS stated that he was interested in observing how object weight and size affected the

Table 9. NYS's sequence of experiments on sinking objects task

	1st	2nd	3rd	4th	5th
Selected objects	•○	●○	•▫	•○	▪◦

● = large steel sphere, ○ = large Teflon sphere, ■ = large steel cube,
□ = large Teflon cube, • = small steel sphere, ◦ = small Teflon sphere,
▪ = small steel cube, ▫ = small Teflon cube.

sinking rate. When asked to predict the outcome, NYS stated that the lighter and larger would sink slower. After observing the large steel sphere sink faster, NYS inferred that the heavier sank faster.

For his forth experiment NYS selected the small steel sphere and large Teflon sphere, indicating that he wanted to observe "the large one may go slower because the large one has more resistance in the water." In NYS' sequence of experiment, NYS inadvertently ran the same experiment two times, for example first and forth experiment. NYS did not attend to previous experiments. NYS chose the small steel cube and small Teflon sphere for his final experiment. After observing the small steel cube sink faster, NYS concluded that being made out of heavy material was important for sinking quickly, but the shape is not a causal factor.

As the above showed, NYS's experiments revealed confirmation bias, is a his tendency to seek information that confirms a weight hypothesis. NYS did not explore the other variables such as size, material.

Ⅳ. Discussion

Formulating Hypothesis. One of the important aspects of constructivism is that students come to the classroom with ideas of their own about the how the world works. These ideas have been developed over time and are used by students to explain a variety of everyday occurrences. In addition, these ideas are elaborate constructs that organize their store of prior knowledge. These constructs often contain belief or relationships between knowledge that do not agree with the constructs of current scientific knowledge.

According to information-processing theories including schema theory (Derry, 1996), having experience is understood and interpreted by creating a mental representation of the experience that is linked to those knowledge structures (schemas) that already exist in memory. The content and structure of the new representation are determined by the interaction between the content of the experience and the structures of the relevant schemas in long-term memory. Therefore, it is certainly true that seventh-graders have a larger amount of previous experience with both natural phenomena and formal school science, as well as a naive understanding of more scientific knowledge than fifth-graders.

Students have strong prior knowledge about the determinants of sinking speed, derived from their everyday experiences such as objects sinking in bathtubs, sinks, swimming pools, objects falling through air, so on. One of the findings in this study is that students' prior knowledge is experienced-based. According to the students' explanations about their own prior knowledge, most knowledges were constructed based on the students' previous personal everyday experiences and observations. These findings are supported by Champagne & Klopfer (1983) who stated that prior knowledge comes from the students' everyday experiences and observations. This prior knowledge seem to persist even when students are exposed to traditional instructional method (Champagne & Klopfer, 1983; Dochy et al., 1999; Driver et al., 1994).

The results of present study showed that most students revised their own prior knowledge in contrast with previous research. 63.0% of fifth-graders and 42.4% of seventh-graders changed their own prior knowledge. These results suggested that the majority of students were likely to modify prior knowledge when they confront prediction phase or experimental simulation. In addition, specific contexts and contents influence the revision of prior knowledge.

Testing Hypothesis. The results of present study showed that a large portion of participants on experimental orientation is the prediction-oriented experiment across task. That is, most students appeared to approach experimentation as an opportunity to demonstrate the correctness of their domain knowledge. In addition, seventh-graders are more likely than fifth-graders to use strategy of hypothesis-oriented experiment.

As in previous developmental studies of scientific reasoning (Penner & Klahr, 1996; Schauble, 1990), the students in the present study quickly concluded, even though participants were free to run simulation. A student working with a hypothesis-oriented intent would be expected to undertake a relatively wide search of the experiment space by exploring all levels of manipulable variables. In contrast, to the extent that a student is working with prediction-oriented intent, he or she is concerned with generating a particular result and may therefore focus on variables judged most likely to affect the outcome, attending only briefly to those presumed noncausal. The result may be narrower search, that is generation of fewer of the possible combinations of variables (Schauble et al., 1991). Schauble and his colleague's results revealed that subjects generated approximately equal numbers of experiments (a mean of about 17), regardless of task or problem context.

One of the findings present study describes students who design inconclusive experiments. This phenomenon, which is analogous to the phenomenon if confirmation bias, shows that subject do not always behave as logical thinkers and do not perform the actions that would be most effective for testing a hypothesis.

Confirmation bias has proved a very robust phenomenon; it has been replicated many times (Kuhn, 1995; Klayman & Ha, 1987; Klahr et al., 1993). Some attempts have recently been made to place confirmation bias in a theoretical framework. An explanation of confirmation bias was advanced by Klayman & Ha (1987) who maintained that subjects' behaviour in a wide array of hypothesis-testing tasks does not reflect a bias that is a general heuristic which they termed 'positive test strategy'. This strategy indeed calls for the generation of test cases which are positive instances of the subject's hypothesis.

Students often inadvertently ran the same experiment two or more times. Although students are notoriously unsystematic in generating combinations in factorial design, there are two reasons why students produced so many repetitions, both suggest that students in the engineering context would generate more repeat experiments (Schauble et al., 1991). First, many students systematically ignored and avoided particular regions of experiment space and instead concentrated their experiments in the region that they believed defined the most effective cases. Second, many students were aware that the outcome measures included small amounts of measurement variance. Thus, students may try to capitalize on trial and error to generate a more favorable outcome.

The findings in this study are similar to those of the Lawson (1992) and Norman (1997) study and provide further empirical evidence that scientific reasoning cannot be viewed as a decontextualized construct.

Evaluating Evidence. The results of this study indicated that the majority of both grade students' conclusions were not supported by confirmatory outcomes. In addition, many students frequently maintained their current hypothesis or prior knowledge in the face of negative or anomalous evidence. The findings in this study are similar to those of the Gauld (1986) study and provide further empirical evidence how students might react to anomalous data so as to make conceptual change more likely. Gauld noted that students distorted their recollection of evidence, transforming their observations to protect their prior knowledge rather than the other way around.

Park et al. (1993) also observed students rejecting evidence when that evidence refuted their prior knowledge. Investigation on evaluating evidence has already been initiated by Kuhn et al. (1988) who focused on what they supposed to be the most central and fundamental skill for scientific investigation, namely, the evidence evaluation that was the process of coordinating theories and evidence. They studied how students managed this coordination and how the coordination process undergoes developmental change.

Chinn & Brewer (1998) present eight typical learners' reaction to anomalous data, of which only one is the adaption of the theory on the basis of the data. Chinn and Brewer maintain that subjects' response to anomalous data is similar at all developmental levels, in line with the common approach that the scientific reasoning processes of children and adult scientists are essentially the same.

One of the reasons why students ignored, rejected, or reinterpreted anomalous data, students thought that there is some probability of error in the experimental outcome received during scientific reasoning task they tend to confirmize their hypothesis against disconfirmation by classifying disconfirming instances as the erroneous trials. Thus, some cases of perseveration may result from students simply not believing the experimental outcome and attributing the apparent disconfirmation to one of several fallible processes.

General Discussion. The goal of this study was to investigate developmental differences in the interaction between children's prior domain knowledge and their scientific reasoning. The results of this study indicate that prior knowledge had a strong effect on students' experimental intent; the majority of participants across grades focused largely on demonstrating the primacy of their prior knowledge or their current hypothesis. In addition, theories that are part of one's prior knowledge have significant impact on hypotheses that are generated, the experiments that are designed, what is considered as supporting and non-supporting evidence, and how hypotheses are revised.

The results of present study indicated that students have difficulty when involved in scientific discovery. There are several possible reasons for this poor showing. First, students may have had little experience in carrying out scientific reasoning. Classroom experiences teachers provided for their students to learn science processes may have involved step-by-step procedures that were given to students to follow in "cookbook" fashion so that they had little opportunity to practice the scientific reasoning themselves (Germann & Odom, 1996). Some teachers may have to learn how to use the science processes themselves before they will be able design appropriate learning experiences for their students.

Staer et al. (1995) survey of 197 science teachers in 28 West Australian schools revealed that in 84% of the practical activities were of the 'cook book' style where the problem to be examined and the investigative approach are described explicitly. It appears then, that most experimental work sets out to illustrate and confirm principles already examined leaving little opportunity for students to develop and practise higher order process skills such as those associated with designing experiments. This may be having deleterious effects on the acquisition of higher order science skills amongst school pupils. Indeed, Hackling and Garnett's (1995) study revealed poorly developed skills in problem analysis, planning and carrying out controlled investigations amongst school children.

Yip (1999a, 1999b) studied assessing the concept of controlled experiments in science teachers. His results suggest that many teachers do not have a clear understanding and consistent rationale for identifying the control in different situations. In addition, science teachers, like their students, are generally capable of handling positive results but experience difficulties in evaluating negative results.

Second, one of possible reasons is referred to prior knowledge. In this study, as previous research has shown, students' prior knowledge have significant impact on formulating hypothesis, testing hypothesis, what is considered as supporting and non-supporting evidence, and how hypotheses are revised.

The representativeness heuristic may influence the scientific reasoning. Representativeness' bias is the tendency for students to classify experimental outcome as either a positive evidence or a negative evidence based on prior knowledge. In addition, the process of anchoring bias occurs when prior knowledge or initial hypotheses are not revised in light of new evidence, contradictory information.

In the present study majority of students liked to test with confirmation bias. These findings have been interpreted as demonstrating that positive tests are biased toward confirmation. Once initial hypothesis or preconception have been formed, it is difficult for students to test accuracy of their hypotheses in an unbiased fashion.

A third aspect of poor scientific reasoning related to neuropsychology. Lawson (1993) found evidence that children's failure to successfully perform on concept acquisition tasks was linked to insufficient operation of the frontal lobes. Given the large increases in the size of prefrontal cortex may be the locus of a system for relational reasoning in humans. This hypothesis is broadly consistent with evidence that prefrontal cortical dysfunction leads to selective decrements in performance on tasks involving hypothesis testing, planning, and problem solving (Waltz, 1999).

A recent study of a specific developmental pattern of prefrontal lobe function has provided further evidence that maturation of the prefrontal lobe continues during adolescence. Thus, young students may have difficulty till maturation of frontal lobe. Other neuroimaging experiments have studied a variety of executive processes including monitoring the contents of working memory, switching between two tasks that both require working memory, applying a complex rule that may be kept active in working memory, and planning a set of moves in a problem-solving task. All of these studies found activation in prefrontal cortex (Smith & Jonides, 1997).

V. Conclusions

The main purposes of this study were: to investigate the interaction between prior knowledge and scientific reasoning in scientific discovery with computerized simulation; to identify a number of characteristic problems that students encounter in scientific discovery. The results of this study indicate that prior knowledge had a strong effect on students' experimental intent; the majority of participants across grades focused largely on demonstrating the primacy of their prior knowledge or their current hypothesis. In addition, theories that are part of one's prior knowledge have significant impact on formulating hypotheses, testing hypothesis, evaluating evidence, and revising hypothesis.

Students' performance was characterized by a number of tendencies: to generate uninformative experiments, to make conclusion based on inconclusive or insufficient evidence, to ignore, reject, or reinterpret negative data, to focus on causal factors and ignore noncausal factors, to have difficulty disconfirming prior knowledge, to have confirmation bias.

Results for this study indicate that students' prior knowledge has a strong effect on their scientific reasoning. In science classroom the two contrasting approaches, that is, domain general knowledge and domain specific knowledge, outlined represent different conceptualizations about what the development of scientific reasoning involves. In some respects, the different approaches reflect a lack of agreement concerning which type of acquisition (i.e., concepts or science process skills) is more important for accounting for developmental differences in scientific reasoning. However, these two approaches have used different types of tasks that emphasize either conceptual knowledge or scientific reasoning. Moreover, science can be characterized as both product and process.

Recently, researchers have begun to investigate scientific reasoning in contexts where this interaction between domain knowledge and general discovery processes can be observed. There are several reasons why science teachers should know the interaction of domain-general knowledge and scientific reasoning. First, as we have already noted, participants are likely to have strong prior knowledge about the causal structure of the domain. Second, the influence of this prior knowledge on participants' hypothesis testing and experimentation skills. Third, most students have difficulty performing scientific reasoning.

In addition, this research has important implications for science educators in particular. Students need an opportunity to perform not step-by-step inquiry that was given to students to follow in "cookbook" fashion, but scientific inquiry that allows them to practice and develops the scientific reasoning skills that will lead to success. Through such practice, they will come to understand that scientific discovery is to determine cause and effect relationships and develop scientific reasoning skills.

References

Alexander, P. A., Kulikowich, J. M., & Schulze, S. K.(1994). How subject-matter knowledge affects recall and interest. *American Educational Research Journal*, 31, 313-337.

Champagne, A. B., & Klopfer, L. E.(1983). *Naive theories and science learning.* Paper presented at the annual meeting of the American Association of Physics Teachers, New York. (ERIC Document Reproduction Service No. ED 300 264).

Chinn, C. A., & Brewer, W. F.(1998). An empirical test of taxonomy of responses to anomalous data in science. *Journal of Research in Science Teaching,* 35 (6), 623-654.

Derry, S. J.(1996). Cognitive schema theory in the constructivist debate. *Educational Psychologist,* 31, 163-174.

Dochy, F., Segers, M., & Buehl, M. M.,(1999). The relation between assessment practices and outcomes of studies: The case of research on prior knowledge. *Review of Educational Research,* 69 (2), 145-186.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P.(1994). Constructing scientific knowledge in the classroom. *Educational Researcher,* 23, 5-12.

Gauld, C.(1986). Model, meters and memory. *Research in Science Education,* 16, 49-54.

Germann, P. J., & Odom, A. L.(1996). Student performance on asking questions, identifying variables, and formulating hypotheses. *School Science & Mathematics,* 96 (4), 192-201.

Gower, B.(1997). *Scientific method: An historical and philosophical introduction.* London, UK: Routledge.

Hackling, M. W. & Garnett, P. J.(1995). The development of expertise in science investigation skills. *Australian Science Teachers Journal,* 41 (4), 80-86.

van Joolingen, W. R., & de Jong, T.(1991). Supporting hypothesis generation by learners exploring an interactive computer simulation. *Instructional Science,* 20, 389-404.

van Joolingen, W. R., & de Jong, T.(1993). Exploring a domain through a computer simulation: Traversing variable and relation space with the help of a hypothesis scratchpad. In D. Towne, T. de Jong, & H. Spada (Eds.), *Simulation-based experiential learning* (pp. 191-206). Berlin, Germany: Springer-Verlag.

Keys, C. W.(1994). The development of scientific reasoning skills in conjunction with collaborative writing assignments: An interpretive study of six ninth-grade students. *Journal of Research in Science Teaching,* 31, 1003-1022.

Klahr, D., & Dunbar, K.(1988). Dual space search during scientific reasoning. *Cognitive Science,* 12, 1-48.

Klahr, D., Fay, A. L., & Dunbar, K.(1993). Heuristics for scientific experimentation: A developmental study. *Cognitive Psychology,* 25, 111-146.

Klayman, J., & Ha, Y. W.(1987). Confirmation, disconfirmation, and information in hypothesis testing. *Psychological Review,* 94, 211-228.

Kuhn, D.(1989). Children and adults as intuitive scientists. *Psychological Review,* 96, 674-689.

Kuhn, D., Amsel, E., & O'Loughlin, M.(1988). *The development of scientific thinking skills.* San Diego : Academic Press.

Kuhn, D., Garcia-Mila, M., Zohar, A., & Andersen, C.(1995). Strategies of knowledge acquisition. *Monographs of the Society for Research in Child Development,* 60 (4), 1-128.

Kuhn, D., Schauble, L., & Garcia-Mila, M.(1992). Cross-domain development of scientific reasoning.

Cognition and Instruction, 9, 285-327.

Lawson, A. E.(1993). Deductive reasoning, brain maturation, and science concept acquisition: Are they linked? *Journal of Research in Science Teaching*, 30 (9), 1029-1051.

Lawson, A. E., Clark, B., Cramer-Meldrum, E., Falconer, K. A., Sequist, J. M., & Kwon, Y. J.(2000). Development of scientific reasoning in college biology: Do two levels of general hypothesis-testing skills exist? *Journal of Research in Science Teaching*, 37 (1), 81-101.

Linn, M. C.(1990). What constitutes scientific thinking? *Contemporary Psychology*, 35, 16-17.

Millar, R., & Driver, R.(1987). Beyond processes. *Studies in Science Education*, 14, 33-62.

Niaz, M.(1992). From Piaget's epistemic subject to Pascual-Leone's metasubject: Epistemic transition in the constructivist-rationalist theory of cognitive development. *International Journal of Psychology*, 27, 443-457.

Niaz, M. (1994). Enhancing thinking skills: Domain specific/domain general strategies-A dilemma for science education. *Instructional Science*, 22, 413-422.

Norman, O.(1997). Investigating the nature of formal reasoning in chemistry: Testing Lawson's multiple hypothesis theory. *Journal of Research in Science Teaching*, 34 (10), 1067-1081.

Novak, J. D.; Gowin, D. B.(1984). Learning how to learn; Cambridge University Press: Cambridge, U. K.

Park, J. W., Chang, B. K., Yoon, H. K., & Pak, S. J.(1993). Middle school student's evidence evaluation about light and shadow. *Journal of the Korean Association for Research in Science Education*, 13, 135-145.

Penner, D. E., & Klahr, D.(1996). The interaction of domain-specific knowledge and domain-general discovery strategies: A study with sinking objects. *Child Development*, 67, 2709-2727.

Reimann, P.(1991). Detecting functional relations in a computerized discovery environment. *Learning and Instruction*, 1, 45-65.

Schauble, L.(1990). Belief revision in children: The role of prior knowledge and strategies for generating evidence. *Journal of Experimental Child Psychology*, 49, 3-57.

Schauble, L., Glaser, R., Duschl, R. A., Schulze, S., & John, J.(1995). Students' understanding of the objectives and procedures of experimentation in the science classroom. *The Journal of the Learning Sciences*, 4, 131-166.

Schauble, L., Glaser, R., Raghavan, K., & Reiner, M.(1991). Causal models and experimentation strategies in scientific reasoning. *The Journal of the Learning Sciences*, 1, 201-239.

Schauble, L., Klopfer, L. E., & Raghavan, K.(1991). Student' transition from an engineering model to a science model of experimentation. *Journal of Research in Science Teaching*, 28 (9), 859-882.

Smith, E. E., & Jonides, J.(1997). Working memory: A view from neuroimaging. *Cognitive Psychology*, 33, 5-42.

Sodian, B., Zaitchik, D., & Carey, S.(1991). Young children's differentiation of hypothetical beliefs from evidence. *Child Development*, 62, 753-766.

Staer, H., Goodrum, D., & Hackling, M.(1995). *High school laboratory work in Western Australia:*

Openness to inquiry. Paper presented at the 26th annual conference of the Australasian Science Education Research Association, Bendigo, Victoria.

Waltz, J. A., Knowlton, B. J., Holyoak, K. J., Boone, K. B., Mishkin, F. S., Santos, M., Thomas, C. R., & Miller, B. L.(1999). A system for relational reasoning in human prefrontal cortex. *American Psychological Society*, 10 (2), 119-125.

Yip, D. Y.(1999a). Assessing and developing the concept of negative experimental results in science teachers. *Australian Science Teachers Journal*, 45 (4), 35-41.

Yip, D. Y.(1999b). Assessing the concept of controlled experiments in science teachers. *Journal of Biological Education*, 33 (4), 204-208.