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A Study on Students Scientific Reasoning in Solving Pendulum Task

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ABSTRACT

The purpose of this study was to investigate the effects of students' prior knowledge on scientific reasoning in solving a pendulum task with a computer simulation. Subjects were 60 Korean students: 27 fifth-grade students from an elementary school and 33 seventh grade students from a middle school located in a city with 300,000 people. This study adapted a pendulum task presented with a computer simulation on which subjects would use a pattern of multivariable causal inferences. The subjects were interviewed individually in a three-phase structured interview by the researcher and three assistants while he/she was investigating the pendulum task. This study showed that most students across grades focused heavily on demonstrating the primacy of their prior knowledge or their current hypothesis. In addition, students' theories that are part of one's prior knowledge have a significant impact on formulating, testing, and revising hypotheses. Therefore, this study supported the notion that students' prior knowledge had a strong effect on students' experimental intent and hypothesis evaluation.

Key words: prior knowledge, scientific reasoning, hypothesis generation, pendulum

I. Introduction

In the field of science learning and instruction, we now see an impressive influence of the so-called constructivistic approach. In this approach, a strong emphasis is placed on the learner as an active agent in the process of scientific knowledge construction. Many science educators believe that students should construct knowledge through inquiry rather than receiving it passively from textbooks or lectures (De Jong and Van Joolingen, 1998; Klein, 1998).

Discovery learning has its roots in Gestalt psychology and the work of Bruner *et al.* (1956). The study of discovery learning has, over the last few decades, moved away from concept discovery (as in Bruner's studies) toward what has been called scientific discovery learning (Klahr and Dunbar, 1988). The scientific reasoning skills serve as a scaffolding during scientific discovery. At the heart of scientific problem solving, scientific reasoning is the processes of formulating hypotheses, testing hypotheses, evaluating evidence, and revising hypotheses (Kuhn *et al.*, 1988).

The development of scientific reasoning skills encompasses two types of knowledge: domain-specific knowledge about the natural world, and domain-general procedures for generating, assessing and integrating that knowledge. When people reason about real-world contexts, their prior knowledge (beliefs) is likely to impose strong theoretical biases. These biases may influence the initial choice of hypotheses in

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hypothesis space (Klayman and Ha, 1987; Schauble *et al.*, 1991). Additionally, prior domain knowledge may influence the experimental strategies utilized to gather new evidence.

Kuhn, *et al.* (1988) have argued that the heart of scientific thinking is the skillful differentiation and coordination of theory and evidence. They have found that young students and many adults do not differentiate between their own theories concerning a phenomenon and the evidence they have gathered. When they were asked to provide support for a theory, these children do not distinguish between testing hypothesis and producing results. In addition, theories that are part of one's prior knowledge have significant impact on hypotheses that are generated, experiments that are designed, what is considered as supporting and non-supporting evidence, and how hypotheses are revised subsequently.

Klahr and Dunbar (1988; Klahr *et al.*, 1993) have used an approach to causal reasoning similar to Kuhn's conception of data-bound thinking, theory-based thinking, and coordination of theory and evidence (Kuhn *et al.* 1992; Kuhn *et al.*, 1995). They consider scientific thinking to be problem solving, which requires searching 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.* (1988, 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 a 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- graders were able to differentiate between hypothetical beliefs and evidence.

To understand why and what students have difficulty when involved in scientific discovery, science educators and cognitive psychologists have pursued several lines of investigation. Typically, they have found that the sophistication of children's inquiry strategies develops with age. Young children often manipulate only those factors that they believe will affect a dependent variable, and fail to hold other factors constantly in order to rule them out as alternative explanations. Young children often retain a prior knowledge when they confront disconfirming evidence, whereas older participants tend to revise their knowledge.

The purpose of this study is to investigate interactions of students' prior knowledge and scientific reasoning while they were engaged in scientific discovery with a pendulum simulation. The objective of this research is to explore students' difficulty, and reasons for the difficulty, involved in scientific discovery, and what is the cognitive source of this difficulty.

Ⅱ. Method

1. Subjects

Subjects were 60 Korean students: 27 fifth-grade students from an elementary school and 33 seventh grade students from a middle school located in a city with 300,000 people. The subjects were selected randomly with approximately equal numbers for each gender. The subjects were diverse with respect to their background. Science experimentation is a major part of their regular classroom program.

2. Scientific reasoning task

A pendulum task was used in this study, which is a scientific reasoning task involving multivariate causal inferences. The task was presented as a computer simulation, which was developed by our research team members. In this study, a simulated pendulum experiment includes three variables. The first one is length with five strings of different length (60, 80, 100, 120, 140 ㎝). The second one is weight with five bobs of different mass (10, 20, 30, 40, 50 g). The third one is height of the dropping point with six angles (20, 30, 40, 50, 60, 70°).

The subjects were asked to manipulate these three variables to complete a given task. The question of interest was: What factors make the speed (frequency) of the pendulum different? theoretically, the speed of the pendulum is inversely proportional to the square root of its length, and no other factors have any measurable effect on the frequency. The pendulum task was presented as a computer simulation. There were only two displays in the simulation. On the control display, the subject uses the computer mouse to choose values of three variables (length, mass, and height). The subject then clicks the "Run" icon to obtain a display of experimental results. This display shows tabular representations of the time with selected values of three variables, after finishing the bob swings back and forth 5 times in pendulum simulation.

The subject can then click the simulation control icon to return to the control page, and then he/she can try new values, and observe the output. Typically, subjects swing back and forth between these two displays, changing variables and observing the result, until they believe they have solved the current problem.

3. Research design and procedure

The fifth- and seventh-grade students participated individually in one 15- to 20-minutes problem session. The subjects were interviewed individually in a three-phase structured interview by the researcher and three assistants while he/she was investigating the pendulum task. All the interviews were videotaped for later analysis. The fifth- and seventh-grade students participated individually in one 15- to 20-minutes problem se

Phase 1: Introduction and initial hypothesis. This phase was designed to investigate students prior knowledge on the pendulum task before presenting the simulation. Subjects were asked what makes a difference in the frequency of the pendulum. The following is a typical direction given to the subjects.

> This is a pendulum. You are going to learn about it. The pendulum has a string here. The object on the bottom is called a bob. When you pull it to the side and let it go forward, it swings, like this. What difference do you think that makes in the frequency of the pendulum? Here, frequency is how long it takes the pendulum to swing back and forth 5 times. That means, what makes it swings fast or slow?

If the subject responded, the interviewer asked "Does anything else make a difference in how fast it swings?". If the subject responded something, the interviewer asked "Why do you think so?".

Phase 2: Simulated experimentation. Subjects were introduced to the pendulum task, and then given an opportunity to test their hypotheses. For each simulated experiment, subjects can change values of three variables. The following is a typical direction given to the subjects.

> You are going to make an experiment on the pendulum simulation. That means that you will change some variables to test whether your thought it is correct or not. Now I would like you to do an experiment to find out what makes the pendulum swing faster or slower. If you want to, you can change the variables. Please do an experiment yourself to find out what makes a differences in how fast the pendulum goes.

Prior to running the simulation, when subjects chose any values of given variables, the interviewer asked, "Tell me about what you are doing" and "why did you chose the values?" After the subjects carried out each trial or appeared finished with the simulation, the interviewer asked, "What have you learned from your experiment? How did you know that? Do you want to explore anything else?"

Phase 3: Consolidation and summary. Following the simulated experimentation phase, subjects summarized their knowledge about relevant causal factors. Subjects were asked to answer what makes a difference in the speed of the pendulum.

After the subject carried out an experiment, he/she was repeatedly asked, "Tell me about what you know from this experiment? What makes the pendulum swing faster or slower?" Before you began this experiment, you said, " …… (e.g., length of string) makes the pendulum swing faster, what are your experimental results?"

Ⅲ. Results

1. Prior knowledge

Subjects were asked what makes a difference in the speed of the pendulum before the computerized task was presented. Subjects' prior knowledge about the attributes that determine the frequency of a pendulum are listed Table 1.

Table 1. Subjects' prior knowledge about the attribute that determine frequency of pendulum.

Subjects responses group	5th-graders (n=27)	7th-graders (n=33)
1. High	25.9	24.3
2. Heavy	18.6	9.1
3. Low	7.4	15.1
4. Short	7.4	15.1
5. Light	7.4	
6. Light and low	7.4	
7. Heavy and short	7.4	15.1
8. Heavy and high	3.7	9.1
9. Light and long	3.7	6.1
10. Heavy, low, and long	3.7	
11. Light, low, and long	3.7	
12. Light, low, and short	3.7	
13. Heavy, high, and Long		6.1
Total	100%	100%

The subject responses to the question about the prior knowledge were categorized into 13 response groups. The subject responses were presented in order from the most frequent response group down to the least frequent group, based on fifth-graders response.

Response group 1, which includes 25.9% of the fifth-graders and 24.3% of the seventh-graders, believed that the higher the drop, the higher the frequency. With regard to their reasons given for their answers, they thought that the higher the dropping point increases the frequency. However in contrast to response 1, response group 3, consisting of 7.4% of the fifth-graders and 15.1% of the seventh-graders, believed that lowering the drop increases the frequency. Both response group 1 and group 3 use three different types of explanations about the relationship between height and frequency. In response group 1, the majority of subjects explanation showed as follows.

M04 (male): Long ago, when I dropped objects at a higher building, the objects dropped faster.

M01 (female): The further back I pull the bob, the faster it will swing because the dropping force might be increased.

E23 (female): Because the moving distance is longer if height is higher.

In the explanation M04 (male, 7th-grader), previous experience accounted for his reasoning. Although M01 (female, 7th-grader) and E23 (female, 5th-grader) thought potential energy or distance were the reasons, they did not recognize the relationship between distance and time.

Both Response group 2 and group 5 claimed that weight of the bob determined swing frequency. Response 2, which includes 18.6% of the fifth-graders and 9.1% of the seventh-graders, thought that the weight of the bob increasing the pendulum will increase frequency. However Response 5, containing 7.4% of the fifth-graders, believed that if the weight of the bob decreases the pendulum's frequency will be increase. In both response group 2 and group 5, the majority of participants' explanations were as follows:

M02 (male, 7th-grader): …because the heavy objects can be accelerated.

M03 (male, 7th-grader): …during the downward swing, the heavier objects' speed increases because of the gravity.

E12 (female, 5th-grader): When the object is moving downward, the heavy object slows from its initial downward speed because it is heavy.

E10 (male, 5th-grader) : When I dropped various objects from the top of an apartment, I observed the heavier object strikes the ground first.

Most of them, who believed weight is a causal factor about the pendulum, used key terms such as gravity and air friction. Among them, E10 explained his reason based on previous experience. This interview data suggests not only that students have various prior knowledge, but also that the sources of prior knowledge are different.

Response group 4, 7.4% of the fifth-graders and 15.1% of the seventh-graders, believed that the length of the string determined the swing speed. All of these participants claimed that if the length of the string decreases, the pendulum would increase frequency because the longer string moves a further distance.

Response group 6, which includes 7.4% of the fifth-graders, thought that being light objects and being low height of the string is important for swing quickly. Response group 7, consisting of 7.4% of the fifth-graders and 15.2% of the seventh-graders believed that being made out of heavy bob and short length string material would be more frequency. The reasons given were similar for both response group 2 and group 4.

Response group 8, consisting of 3.7% of the fifth-graders and 9.1% of the seventh-graders, believed that being made out of heavy bob and high dropping material would be faster. The reasons given were similar to both response group 1 and group 2. Response group 9, which includes 3.7% of the fifth-graders and 6.1% of the seventh-graders believed that being made out of light bob and long string would be faster. The reasons given were similar to group 5.

Response group 10, group 11, and group 12 include 3.7% of the fifth-graders respectively. All of these subjects claimed that all of three variables affected swing frequency. Response group 13, containing 6.1% of the seventh-graders, believed that being made out of light bob and short string and being low dropping would be faster.

2. Stability of prior knowledge

In order to assess the stability of prior knowledge, students' initial probe was examined. The percentage of consistency with prior knowledge was classified by grade according to change or consistency with prior knowledge. The result shows 37.0% of the fifth-graders changed their own prior knowledge suggested by their initial probe, and the remaining 63.0% of the fifth-graders were consistent with their prior knowledge. In contrast with the fifth-graders, 78.8% of the seventh-graders changed their own prior knowledge, and the remaining 21.2% of seventh-graders were consistent with their prior knowledge. The Pearson Chi-square analysis indicated a significant relationship between change and consistency patterns (x^2 = 10.78, $p < 0.01$).

3. Experimental rationale

Each experiment was coded with respect to not only the student's explicitly stated intent, but also the intent suggested by three or more of their trials. Hypothesis-oriented experiments included statements about investigating the effect of an attribute, such as, "I wonder if weight of the bob has something to do with it." In contrast, prediction-oriented experiments were accompanied only by statements about the predicted outcome, such as, "the heavier bob will swing faster (Penner and Klahr, 1996)."

The result shows 18.5% of the fifth-graders and 21.2% of the seventh- graders were classified as hypothesis-oriented, while the remaining 81.5% of the fifth-graders and 78.8% of seventh-graders were classified as prediction-oriented. The difference between the grades and the experimental intent were not statistically significant ($t = 0.72$, $p > 0.05$).

4. Breadth of Experimentation

A student working with a hypothesis-oriented intent could be expected to undertake a relatively wide search of the experiment space by exploring all levels of manipulable variables, when compared to those with a prediction-oriented intent. The number of trials was counted, and then compared by grade and across task.

Table 2 shows that the differences between the fifth- and the seventh-graders' number of trials on pendulum task were not statistically significant in t-test analysis ($p > 0.05$). Although there was no significant difference in the trial numbers between the fifth- and the seventh- graders, the trial numbers of seventh-graders ($M = 6.27$, $SD = 2.77$) was higher than the fifth-graders ($M = 5.85$, $SD = 3.22$). In addition, there was no significant difference between the experimental intent and the number of trials.

Table 2. t-test analysis of number of trials about pendulum task

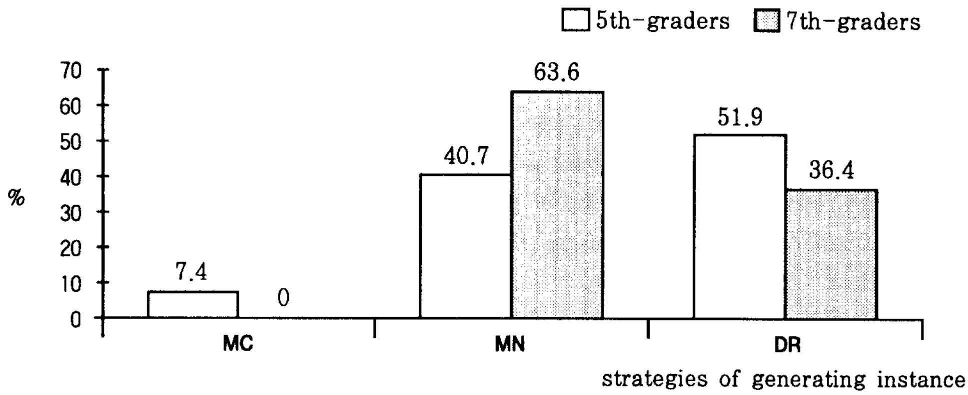
	N	Mean	SD	t-value	p
5th-graders	27	5.85	3.22	0.54	0.59
7th-graders	33	6.27	2.77		

5. Controlling variables

In a pendulum task, the independent variables consisted of weight, height, and length. If students 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 three types of generating instance strategies, which require rule induction: maintaining causal variable strategy (MC), maintaining noncausal variable strategy (MN), desultory and rule inductive strategy (DR). MC strategy is that the variables, which are believed to be causal, are keep constant, while the remaining variables are manipulated. MN strategy is that the variables which are believed to be noncausal, are keep 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.

A bar graph comparison of the percentage of generating instances strategy on pendulum task is shown in figure 1.



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

Fig. 1. Comparison of generating instance strategies

In this figure, 7.4% of the fifth-graders used MC strategy on pendulum task, while none of the seventh-graders used this strategy. The fifth-graders used DR strategy more than the seventh-graders. However, the majority of the seventh-graders employed the MN strategy.

6. Confirming final conclusion

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

In this study, the majority of both grade participants' conclusions were not supported by confirmatory outcomes. In addition, older graders seemed to have more confirming conclusions supported by confirmatory instances than younger students. Pearson Chi-square analysis indicated no significant relationship between the grades and the experimental support.

7. Prior knowledge and scientific reasoning

The investigation of the students' prior knowledge that affects the initial hypothesis, interpreting data, final conclusion is described here. It is shown in Figure 2, which is a flow chart comparison of the percentage of how the prior knowledge affects scientific reasoning.

In the hypothesis space of Figure 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.

In Figure 2, 14.8% of the fifth-graders' and 15.2% of the seventh-graders' initial hypotheses and final conclusion were affected by their prior knowledge about pendulum task. In addition, 37.0% of the fifth-graders' and 36.4% of the seventh-graders' initial hypotheses were affected by their prior knowledge. However, interpreting data and final conclusion were not affected by prior knowledge about pendulum task.

The major feature of Figure 2 was that participants' initial hypotheses, 66.6% of the fifth-graders and 66.8% of the seventh-graders, were affected by prior knowledge. In addition, the figure suggested that when the one-third of the fifth- and seventh-graders drew the conclusion in their scientific reasoning, student's prior knowledge affected his/her experimental conclusion. The patterns of scientific reasoning affecting by prior knowledge were similar to both fifth- and seventh-graders.

Ⅳ. DISCUSSION

The purpose of this study was to investigate the interaction between children's prior knowledge and hypothesis testing strategies. Although there are limitations to any cross-domain generalizations possible from the study of a single micro-domain, this initial probe enabled us to explore scientific reasoning and the strategies of knowledge construction of students.

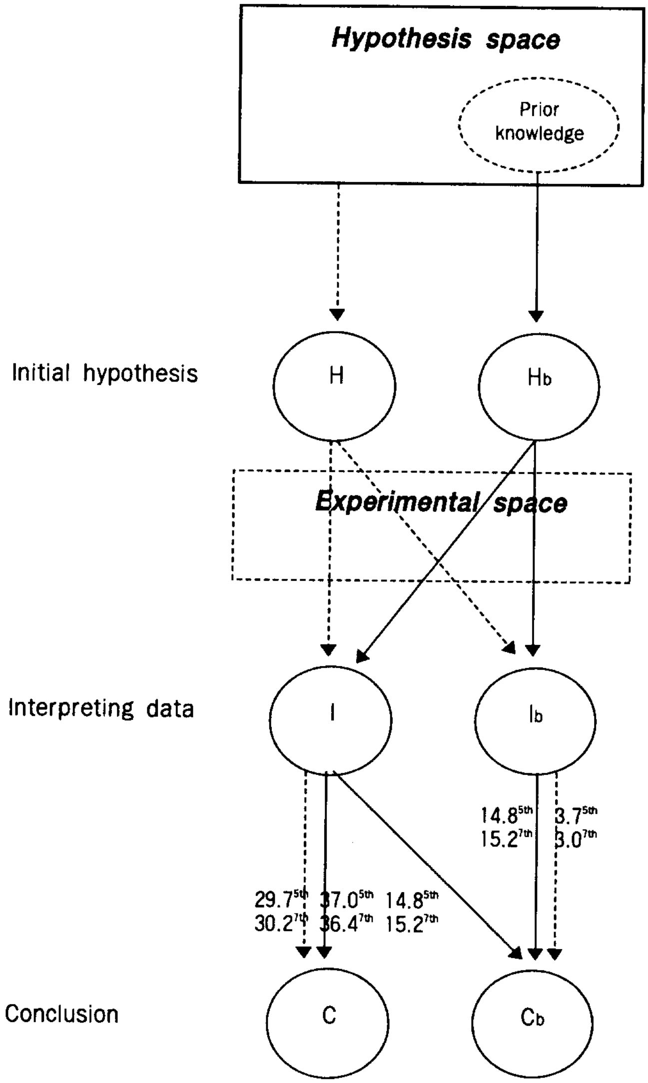


Fig. 2. Pattern of scientific reasoning affected by prior knowledge

The results obtained in the present research show not only that participants' prior knowledge had significant impact on hypothesis testing such as design of experiments and interpretation of experimental outcomes, but also that participants were more likely to attend to information concerning variables believed to be causal over noncausal. The former is a confirmation bias, and the latter is a causal bias. These findings are consistent with previous research reporting (Klayman and Ha, 1987; Kuhn *et al.*, 1988; Schauble *et al.*, 1991).

These results suggest that individuals do not come to a scientific discovery task as blank slates that systematically search the problem space. Instead, they bring domain-specific content knowledge that they apply to the task. These biases tend to limit students' exploration of the problem space. As in previous studies, for examples Klahr *et al.* (1993), Kuhn *et al.* (1995), and Penner and Klahr (1996), our participants generally do not think that fully exploring the dimensions they do perceive is necessary, thereby ignoring noncausal variables and missing interaction between variables and evidence that would disconfirm their held beliefs. For this reason, children in the present study quickly concluded that they understood the pendulum task.

In this study, we identified that participants prefer predictive-oriented testing strategy; that is, most participants often view experimentation as a means of demonstrating the correctness of their prior knowledge, rather than proving a hypothesis. These inefficient experimentation behaviors were called engineering approach by Schauble *et al.* (1991). This engineering approach was also found by Schauble *et al.* (1995), Njoo and De Jong (1993), and Penner and Klahr (1996). An engineering approach, as compared to the scientific approach, leads to a much narrower search and to a concentration on those variables that success guaranteed. As a consequence, this approach may prevent learners from designing experiments that provide well-organized data that are sufficient for discovering all relevant domain relations.

For knowledge revision, most of our participants revised their prior knowledge during the scientific discovery process. The findings of the present study are in sharp contrast with some in the recent literature on knowledge revision (e.g., Penner and Klahr, 1996; Kuhn, *et al.*, 1995) that children's prior knowledge does not changes during the course of experimentation.

There are several reasons why most of our participants modified their prior knowledge as conflicting with previous studies. First, children had weak prior knowledge about the causal structure of the pendulum task while they had strongly held beliefs about the task of previous studies, such as sinking object (density). Second, both the hypothesis spaces and experiment space may be very small, or consist of easily accessible (i.e., highly plausible) hypotheses.

Consequently, hypotheses testing is not only generally recognized as a difficult process, but also showed poor performance. What is the source of this difficulty? One of the reasons is that students lack of experience with this scientific discovery may have interfered with their performance. Science teachers who provided for their students to learn science processes may have involved step-by-step procedures that were given to students to follow in a "cookbook" fashion so that they had little opportunity to practice the science processes themselves. Staer *et al.* (1998) survey of 197 science teachers in 28 West Australian schools revealed that 84% of the practical activities were of the 'cookbook' style where the problem to be examined and the investigative approach are described explicitly.

Similar results were described by Germann *et al.* (1996). It appears that most experimental work sets out to illustrate and confirm principles already examined, leaving little opportunity for students to develop and practice scientific reasoning. This may be having deleterious effects on the acquisition of higher order scientific skills.

V. Conclusions

The main purpose of this study was to investigate the interaction between prior knowledge and scientific reasoning in scientific discovery with a computerized simulation. 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 hypotheses. 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 in disconfirming prior knowledge, to have confirmation bias and inference bias.

In this research, we identified several problems that students encountered in the discovery process. For the process of hypothesis generation, a learner' s weaknesses includes choosing hypotheses that seem to be safe, and unsuccessfully transforming data into a hypothesis. For designing experiments, we found learners who showed inefficient experimentation behavior, who followed both confirmation bias and causal bias, and who applied an engineering approach instead of a scientific one. Furthermore, learners quite often have trouble with the interpretation of data as such.

This research has important implications for science educators in particular. Students need an opportunity to perform not step-by-step inquiry that were given to students to follow in "cookbook" fashion, but scientific inquiry that allows them to practice and develop 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 affect relationships and develop scientific reasoning skills

References

Bruner, J. S., Goodnow, J. J., & Austin, G. A. (1956). *A study of thinking*. Wiley, New York, 330 p.

De Jong, T., & Van Joolingen, W. R. (1998). *Scientific discovery learning with a computer simulations of conceptual domains. Review of Educational Research*, 68(2), 179-201.

Germann, P. J., Haskins, S., & Auls, S. (1996). Analysis of nine high school biology laboratory manuals: Promoting scientific inquiry. *Journal of Research in Science Teaching*, 33(5), 475-499.

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.

Klein, P. D. (1998). The role of children' s theory of mind in science experimentation. *Journal of Experimental Education*, 66(2), 101-124.

Kuhn, D., Amsel, E., & O'Loughlin, M. (1988). *The development of scientific thinking skills*. Academic Press, London, 249 p.

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.

Njoo, M., & de Jong, T. (1993). Exploratory learning with a computer simulation for control theory: Learning processes and instructional support. *Journal of Research in Science Teaching*, 30, 821-844.

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

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

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.

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. (1998). High school laboratory work in Western Australia: Openness to inquiry. *Research in Science Education*, 28(2), 219-228.