New Physics: Sae Mulli,
Vol. 68, No. 4, April 2018, pp. 387∼396
http://dx.doi.org/10.3938/NPSM.68.387

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Effects of Students' Background Knowledge and Methodological Belief on the Process of Finding the Relationship between Measured Data

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(Received 6 December 2017 : revised 22 March 2018 : accepted 28 March 2018)

This study investigated whether background knowledge and methodological beliefs affected students' interpretation of volume and temperature data for an ideal gas. To this end, we provided 22 pre-service science teachers with real measurement data and asked them to derive the relationship between the two variables. First, the pre-service teachers (hereafter referred to as students) were divided into two groups; one was given information about the variables, and the other was not. When information on the variables was provided, more students were able to propose a relationship consistent with their background knowledge, indicating that background knowledge affected the interpretation of data. Secondly, to examine the influence of methodological belief, we used Likert-scale questions to determine whether students considered a simple scientific law or an accurate law to be better. We found that they tended to suggest a relationship in a manner consistent with their methodological beliefs. Based on these results, further research is proposed to investigate the effect of other possible methodological beliefs on scientific inquiry.

PACS numbers: 01.40.ek, 01.40.fk, 01.50.Pa
Keywords: Background knowledge, Interpretation of data, Methodological belief, Nature of scientific inquiry, Relationship between variables

I. INTRODUCTION

The purpose of this study is to investigate how students derive, infer, or find out the relationship between variables from quantitative data and what factors influence the process of deriving that relationship.

From a philosophical perspective, the process of science can be viewed as a context of discovery and a context of justification [1], and this study is related to the context of discovery. Popper [2] argues that the creation of new scientific knowledge is not a logical process but a psychological interest [2]. However, a more detailed understanding of the process of constructing new scientific knowledge is important [3], and in fact, Simon argues that the process of discovery is logically understandable [4]. In the scientific inquiry process, discovering new observations, proposing new inquiry problems, suggesting new hypotheses, or deriving the new relationship between variables from measured data are the processes that contribute significantly to the context of discovery. Therefore, understanding these inquiry processes can play an important role in planning how we can help students to discover and construct new scientific knowledge.

Among the various inquiry processes contributing to the context of discovery, this study is interested in the process of finding relationships between variables from quantitative data. "Analyzing and interpreting data" has been emphasized by scientific educators as one of the key skills of scientific inquiry [5–7] as well as by the Framework for K-12 Science Education [8]. However,

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there have been very few studies investigating the stages or key characteristics in the processes that secondary students use to derive relationships between variables from quantitative data.

The process of finding relationships between variables can be divided into a bottom-up process and a top-down process. The bottom-up process emphasizes the logical and formal relationship of finding relationship between variables from data. Therefore, in the case of this process, the investigator is mainly concerned with the nature of the data itself, and seeks to find and apply appropriate strategies for finding hidden features in the data. The studies of Langley [9] and Langley *et al.* [10] focused on the bottom-up process. For example, if two variables increase or decrease in line with each other, we can find a proportional relationship between these variables using a strategy of dividing these two variables. Moreover, if one variable decreases when the other increases, then an inversely proportional relationship can be found by using a strategy of multiplying the two variables. When Qin and Simon asked students to analyze Kepler's data [11], they observed that students used strategies similar to the methods of Langley *et al.* [10]. As a result, 9 out of 14 students who used the strategies reported an exact relationship.

Another example of a bottom-up process is finding the trend-line closest to the measured data. However, these strategies are not the only way to find a relationship. For example, when Ptolemy measured the incident angle (i) and refraction angle (r) of light between air and water, the trend-line closest to the measurement result was "$r = 0.0025i^2 + 0.825i - 4 \times 10^{-14}$" [12]. However, the physically meaningful relationship was "$\sin r = (1.33)\sin\ i$".

In the case of a top-down process, the scientist has a strong interest in the physical meaning of the relationship between the variables, and thus the interaction between the data and background knowledge plays an important role in this process. Furthermore, in this process, finding the relationship between variables from the data is not always seen as a mechanical and logical process. For example, according to Franklin's analysis, Millikan did not use 49 of the 107 data points obtained after March 13, 1912, and made some modifications to 30 of the 58 data points used [13]. Moreover, he did not report the data obtained on April 16, 1912, which were inconsistent with a previous result. Of course, it emerged that this error occurred because too much charge was applied. In other words, in the process of finding a physically meaningful result, an investigator may not use data that seem problematic, rather than mechanically processing the measured data.

Of course, the top-down process also starts with data, but a temporary solution is then proposed as a physically meaningful solution, and the process of revising and complementing the temporary solution by comparing it with the data is progressed. For example, Kim, Lee, and Park observed that after students had identified the characteristics of the data, they first proposed an approximate temporary solution that was close to the characteristics of the data, and showed the deductive process of modifying the temporary solution by comparing it with the data [14]. This deductive process can be seen as a top-down method. In this process, the analyzing and interpreting of data can be viewed basically as a process of coordination between theory and data. In this regard, Chinn and Brewer state, "We assume that when individuals evaluate data, they first construct a cognitive model that integrates data and theoretical interpretation." [15].

In recent years, the process of deriving relationships between variables from the measured data has become very simple due to the development of computers and related programs. For example, Excel program can easily display the measurement data in graph form, and create a formula describing the relationship between the variables as a trend-line. However, it is not always easy to ascertain the relationships between the variables and to obtain useful information. For example, if the data do not appear as a simple value [16], if the volume of data is vast [17], or if there are more than two independent variables [14], and because all measurement data contain basic errors [18], data analysis is not always automatic. From this, it can be inferred that other factors besides mechanical and mathematical processes will affect the process of data interpretation. Therefore, the basic aim of this study is to explore various hidden factors that may affect the process of data interpretation.

Table 1. Measurement data presented to students.

Variable	Data									
Independent variable A	1.3	1.5	2.4	1.8	0.4	0.8	3.3	0.6	3.1	0.2
Independent variable B	0.8	1.0	1.3	1.6	1.9	2.3	2.6	3.0	3.3	3.7
Dependent variable C	7.3	7.0	8.1	6.1	3.0	3.7	7.0	3.0	6.1	1.6

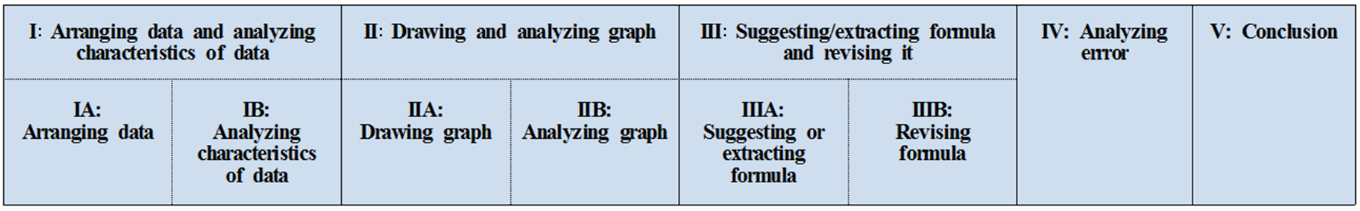

Fig. 1. (Color online) Thinking stages for deriving the relationship between variables.

II. PREVIOUS STUDY AND RESEARCH GOALS

Kim, Lee, and Park presented scientifically gifted high school students with quantitative data for two independent variables and one dependent variable (Table 1), and asked them to find the relationship between the variables from the data [14]. Based on the students' responses, they analyzed various characteristics in the process of data interpretation.

In Table 1, the two independent variables were the cross-sectional area and mass of a falling object under air resistance, while the dependent variable was the object's terminal velocity. However, the researchers did not inform the students what each variable in fact comprised, but only described the independent variables as A and B, and the dependent variable as C. The reason was because the previous research was interested in the bottom-up process of finding the relationship between measured data. Therefore, we tried to find out what stages and strategies students were used to find the relationship, without being influenced by other factors such as experimental situations, theories related to the experiment, and so on. As a result, the students' thinking process was divided into five stages as shown in Fig. 1.

During these five stages, the thinking strategies used by the students could be divided into eight types. Of these, the strategy (multiplication or division of two variables) proposed by Langley *et al.* was used by 11% of the students, while 73% first analyzed the characteristics of the data, and 68% suggested the hypothesis first and

$$\mathrm{C} = \frac{6-(\frac{A}{B}+B)}{\frac{A+B}{AB}\times\frac{1}{2.8}}, \quad C = (\sqrt{\frac{A}{B}}+1)^{2.5}, \quad C = 1.4998A - 1.3717B + 5.9259$$

Fig. 2. Some examples of complex or detailed relationships proposed by students.

then modified the hypothesis by comparing it with the table [10]. In other words, students began to use the bottom-up approach to extract the characteristics of the data when they first encountered the data, but then immediately proposed a temporary relationship and used a top-down approach by revising the initial idea. In addition, some errors used by students were also found in the process of data analysis.2

In this previous study, Kim, Lee, and Park observed one interesting result: Approximately half of the students suggested complex relationships between the variables in various ways [14]. For example, as shown in Fig. 2, either the form of the relationship was too complex, the exponent value contained in the relationship was very detailed, or constant values in the relationship were too detailed.

This study was conducted to ascertain why students proposed such overly detailed or complex relationships. To this end, we proposed two hypotheses. First, when presenting data to students, they could not use the background knowledge related to the data because the researcher did not tell them how the data had been obtained or what the data were about. Therefore, students could not judge the physical meaning of a relationship, but had to focus on the data themselves. As a result, they tried to derive a relationship that was faithful to the data. In other words, the first hypothesis of this study is that "background knowledge has an effect on the finding of a relationship between variables from quantitative data."

This hypothesis is plausible according to other studies that show that background knowledge affects data interpretation in the process of scientific inquiry. For example, although the data were qualitative, Kuhn, Amsel, and O'Loughlin reported that when evaluating evidence, students based their evaluations on their own prior ideas as well as on the data themselves [19]. In this regard, Park and Pak observed that students gave more idea-based responses if they thought that the independent variables were irrelevant to the dependent variables, compared to when two variables were considered to be related to each other [20]. Shah and Hoeffner also reported that prior ideas influenced graph interpretation [21]. Shah observed that the investigators concluded that drunk driving and car accidents were related to each other, despite being presented with a graph that showed no relationship between them [22]. If the measurement result is inconsistent with the prior idea of the investigator, the effect of the prior idea may play a greater role [5]. For example, Lin observed that, when college students were presented with data that conflicted with their prior ideas, they rejected that data (56%), pointed out uncertainty in the validity of interpretation (18%), reinterpreted the data, stopped judgment (11%), and so on [23]. In this regard, physicist Dirac has suggested that, although there is a discrepancy between theory and experiment, "one should not allow oneself to be too discouraged, because the discrepancy may well be due to minor features that are not properly taken into account..." [24].

The second hypothesis is that the "methodological belief that a scientific relationship needs to be as simple as possible can have an effect on finding a relationship between variables from quantitative data." In the previous study of Kim, Lee, and Park, 5 out of 40 students who mentioned these rules actually proposed a simple form of relationship [14].

The plausibility of the second hypothesis can be deduced from the components of Kuhn's paradigm. According to Kuhn, there are five components of the paradigm: basic laws and theoretical assumptions, experimental or instrumental techniques, metaphysical principles, and methodological prescriptions [25]. Here, as an example of methodological prescription or rule, Chalmers describe show one should "Treat failures in attempts to match your paradigm with nature as serious problems." [25]. Therefore, our second hypothesis corresponds to students' beliefs about the methodological prescription or rule. In this study, we call these the students' methodological beliefs.

The belief that "Simple scientific laws are better" may serve as a fundamental direction of physics research. The basic reason why Galileo introduced idealization as a systematic scientific method is because simplification is a useful way to understand complex nature [26]. McMullin stated, "When Galileo was faced with complex real-world situations, however, he was 'idealized' in more specific ways [27]. That is, he shifted the focus to a simpler analogue of the original problem." Zuckerman also found, through interviews with Nobel Prize laureates, that many scientists "identified 'simplicity' of solutions as a mark of scientific taste." [28].

Here, we have distinguished between the meaning of "simple scientific law is better" and the meaning of "If possible, it is necessary to find a simple relationship from the complex data", although this is not strict. The former corresponds to aesthetic or epistemological belief, while we regard the latter as a methodological belief. Because this study focuses on the analysis process of data during the inquiry process, we chose the latter viewpoint.

Based on the above background, the research goals are:

- to examine whether background knowledge related to measurement data has an effect on deriving a relationship between variables.

- to examine whether methodological beliefs related to data interpretation have an effect on deriving a relationship between variables.

III. METHOD

1. Sample of Research

The participants in this study comprised 22 college students (pre-service teachers) in a department of science

Table 2. Actual data of gas volume and pressure obtained by Boyle (Langley *et al.*, 1992, p. 82).

Volume (V)	Pressure (P)	PV
1.0	29.750	29.750
1.5	19.125	28.688
2.0	14.375	28.750
3.0	9.500	28.500
4.0	7.125	28.500
5.0	5.625	28.125
6.0	4.875	29.250
7.0	4.250	29.750
8.0	3.750	30.000
9.0	3.375	30.375
10.0	3.000	30.000
12.0	2.625	31.500
14.0	2.250	31.500
16.0	2.000	32.000
18.0	1.875	33.750
20.0	1.750	35.000
24.0	1.500	36.000
28.0	1.375	38.500
32.0	1.250	40.000

education (mean age = 22.6), who were taking courses related to science education offered by one of the researchers. Participants were randomly selected to participate in the study, and were willing to participate. Of the sample, one student, who failed to draw the conclusion about the relationship between variables, therefore, this student was excluded from the analysis.

2. Instruments

The quantitative data presented to students in this study comprised real data about gas volume and pressure, obtained by Boyle [10]. These data appear to be approximately inversely proportional, but due to measurement errors, when the two variables are divided according to the strategy of Langley *et al.*, they do not show a constant value as shown in Table 2 [10]. As a result, when the trend-line is analyzed using Excel, it does not appear as a simple proportion as shown in Fig. 3. Students were also allowed to use a calculator or program for data analysis. Therefore, if students focus faithfully on the data, they may suggest a complex relationship between the variables.

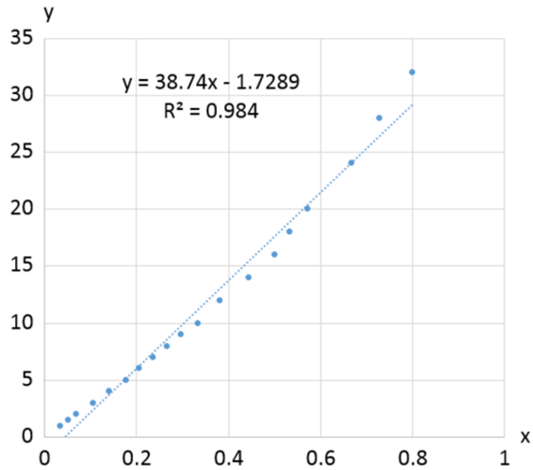

Fig. 3. (Color online) Trend line by Excel program (x axis means 1/P and y axis means V).

3. Design to Investigate the Effect of Background Knowledge

To ascertain whether or not background knowledge affected the students' derivation of the relationship between variables from the measured data, the 22 students were divided into two groups of 11 students each. In group I, the students were provided with information about the two variables, that is, that one variable described gas volume and the other gas pressure. In contrast, in group II, the students were not provided with any information about the variables, but instead the variables were labelled "A" and "B", respectively.

4. Design to Investigate the Effect of Methodological Belief

The 22 students were asked to respond to a Likert scale question, as shown in Fig. 4, to ascertain how methodological belief affected their derivation of the relationship between variables. We have tried to secure the content validity of the question in Fig. 4 by discussing repeatedly whether the content of the question is valid for the purpose of the study, whether the question is interpreted differently by respondents, and so on.

The students' methodological beliefs were calculated as 5 points for "strongly agree", 4 for "agree", 3 for "neutral", 2 for "disagree", and 1 for "strongly disagree".

Table 3. Students' derived relationships between variables (n = 21).

Type of Relationship		Examples of Responses	No. of Responses
Simple relationship	Inversely proportional	(S7) As the volume increases, the pressure gradually decreases, and the average of the product of volume and pressure is approximately 31.57. Thus, volume and pressure are inversely related to each other.	9 (5/4)*
	Approximately inversely proportional	(S3) We cannot say that it is completely inversely proportional, but we conclude that the overall shape [of the graph] is inversely proportional since the higher the volume, the lower the pressure.	3 (3/0)
	Inversely proportional including errors	(S15) The volume and pressure of the ideal gas are inversely proportional to each other. ... [but] the control of variables would not be correct and could not obtain accurate measurements.	3 (2/1)
Complex relationship	Complex form	(S11) A is proportional to $\log(1/B)$	3 (0/3)
	Complex constant values	(S4) The relation between A and B has a power form because it can be expressed by the equation of the trend-line, $y = 26.356x^{-0.915}$	3 (1/2)

* The first and second numbers in parentheses indicate the number of students in group A and B, respectively.

Scientists attempt to understand, explain, and predict nature. In fact, the nature that scientists investigate is often very complicated. In this situation, what do you think of the following two scientists' research methods?

Scientist 1: To understand nature properly, it is important to know it as accurately and precisely as possible, even if it is complex.

Scientist 2: Since it is important to know the essence of nature, it is important to find out as simple a rule as possible for the major factors.

1. Please respond to the table below.

	Strongly agree	agree	neutral	disagree	Strongly disagree
Scientist 1	( )	( )	( )	( )	( )
Scientist 2	( )	( )	( )	( )	( )

2. Please describe the reason.

Fig. 4. Questions used to check the effect of methodological belief.

When investigating students' methodological beliefs, students were asked to choose just one of the two scientists' perspectives in Fig. 4. In this case, however, this may have resulted in a forced response. In fact, students may agree or disagree with both scientists' perspectives to different degrees. Thus, this study asked students how much they would agree or disagree with each of the two perspectives.

5. Data Analysis

First, students' relationships were classified into either "simple relationship" or "complex relationship." In other words, when the relationship between volume and pressure is simply inversely proportional, it is classified as a "simple relationship". And when the relationship is inversely proportional to square root, logarithmic, or contains complicated constant value, it is classified as a "complex relationship".

To investigate the effect of background knowledge, we analyzed whether there was a difference in the form of the relationship (complex relationship or simple relationship) between the group that received the information about the variables (corresponds to background knowledge) and those who did not. In order to check if methodological beliefs were influential, we analyzed whether there was a difference in the total score of responses to methodological beliefs between students who proposed a simple relationship and students who proposed a complex relationship. For statistical analysis, a χ^2-test and t-test were performed using SPSS (20.0.0).

IV. RESULTS

1. Students' Derived Relationships Between Variables

Apart from one student who failed to draw a conclusion about the relationship, the relationships derived by the students from the quantitative data are as shown in Table 3, and they can be divided into the simple relationship, showing an inversely proportional relationship,

Table 4. The effect of background knowledge on deriving the relationship between variables.

Data condition	No. of students who derived the following conclusion	
	Simple relationship	Complex relationship
Information about variables not given	5	5
Information about variables given	10	1

$\chi^2 = 4.296$, $p = .038$.

Table 5. Students' Responses about Methodological Belief.

Type	No. of students					Average
	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	
A	6	8	6	1	0	0.9
B	8	9	3	0	1	1.1

Type A: Accurate relationship is better. Type B: Simple relationship is better.

and the complex relationship. Furthermore, each relationship can be divided into 2–3 subcategories.

2. The Effect of Background Knowledge

Table 4 shows the results for examining the influence of background knowledge when suggesting relationships between variables from quantitative data.

According to Table 4, when no information about variables was given, there was no difference between the simple relationship that the two variables were inversely proportional (5 students) and the complex relationship (5 students). However, when variable information was given, 10 students proposed a simple relationship, while only 1 student suggested a complex relationship. And moreover, the difference between these responses was statistically significant ($\chi^2 = 4.296$, $p < .05$).

In fact, if we look closely at the relationship between the two variables, following conclusion is possible; "The variable 'V' is proportional to the square of the variable '1/P'." as shown in Fig. 5. And the trend line in Fig. 5 matches more data compared to the trend line in Fig. 4.

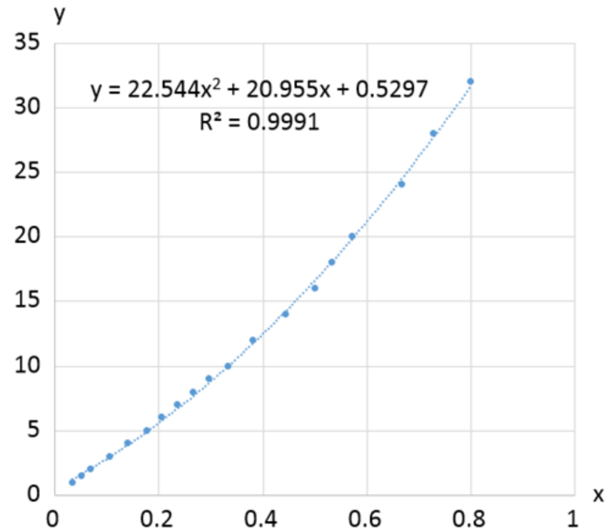

Fig. 5. (Color online) More detailed trend line by Excel program (x axis means 1/P, y axis means V).

Nonetheless, the reason that they concluded that the two variables were inversely proportional was because they already knew the relationship between the pressure and volume of ideal gas. As a result, this result indicates that background knowledge about the variables affected the students' conclusions about the relationship between variables.

When asked whether the relationship between variables needs to be accurate (Type A) or it is important to find the simple relationship (Type B), the average responses of students was nearly the same for both beliefs, at 0.9 and 1.1, as shown in Table 5.

3. The Effect of Methodological Belief

Table 6 shows the average scores for methodological beliefs between students who suggested a simple relationship, that they were inversely proportional, and students who proposed a complex relationship.

According to Table 6, students who suggested a simple relationship showed a higher average score (4.33) in the methodological belief that finding a simple relationship is better (Type B) than the average score (3.80) of the methodological belief that finding an accurate relationship is important (Type A). This difference was statistically significant ($t = 1.948$, $p < .05$). On the other hand, students who presented complex relationships showed a

Table 6. The effect of methodological belief on deriving the relationship between variables.

Conclusion	Average score of methodological belief		df	t	p (one-tailed)
	Type A: Accurate relationship is better	Type B: Simple relationship is better			
Simple relationship (Inversely proportional)	3.80	4.33	28	1.948	.030*
Complex relationship	4.17	3.50	10	0.904	.194

$^{*}p < .05$.

higher average score (4.17) in the methodological belief of Type A than an average score (3.50) in the methodological belief of Type B. However, this difference was not statistically significant ($t = 0.904$, $p > .05$) because the number of responses was too small.

Although the difference in beliefs was not statistically significant in the case of the group who suggested a complex relationship, based on the pattern of responses, we can infer that methodological beliefs have an effect on finding the relationships between variables.

V. DISCUSSION

From this study, it was found that the background knowledge related to the measurement variables influenced the process of deriving the relationships between variables from the quantitative measurement data.

This result can be found in other types of inquiry skills as well as interpretation of data. For example, scientific observations themselves depend not only on sensory information stimuli but also on background theories related to the observed objects [25,29]. They are also selective based on the observer's intention or goal of observation [30,31], and can often be distorted by the observer's background knowledge or predication [32]. The results of this study support the view that inquiry activities are an active interaction between inquiry skills and related theories [33–35].

When we divide the process of deriving the relations between variables from the measured data into the bottom-up process and top-down process, the fact that background knowledge affects the process of deriving relationships means that this process occurs as a top-down process. Of course, the bottom-up process is also important for exploring what features or trends are basically present in the measurement data. However, the result of this study implies that the investigator does not simply mechanically derive the relationship between the variables. In this regard, Shah and Freedman observed that students used the two processes complementarily in the interpretation of data and graphs [16].

Particularly, in this study, the relationship between gas volume and pressure comprises easy knowledge for college students. Therefore, although we provided information about just two variables to the students, they could easily ascertain the relationship between the variables. Therefore, it can be inferred that the influence of this background knowledge played a larger role. However, this study did not confirm through interviews whether the student's background knowledge actually influenced the interpretation of the data. And even if the background knowledge influenced the interpretation of the data, we did not explore how the students interpreted aspects, such as errors contained in the data, which are inconsistent with background knowledge. Therefore, further studies will be required to supplement this point.

And also, instead of direct background knowledge about the relationship between variables, if only background knowledge related to the variables, or background knowledge about the experimental situation were provided, it would be meaningful to investigate how the influence of background knowledge varies depending on the type and relevance of that knowledge.

Although we did not obtain enough responses for statistical confirmation, the second major result of this study is that methodological beliefs may influence derivation of the relationship between variables. According to the perspective that students' conceptual framework can be viewed as a conceptual ecology consisting of epistemological commitments, metaphysical beliefs, experiences, and so on [36,37], inquiry activity is also viewed as an ecological system in which methodological beliefs interact with both inquiry skills and background knowledge. However, there have been few studies on the effect of methodological beliefs on inquiry activities. Therefore, more extensive studies on this point are required. For example, the following methodological beliefs related to scientific inquiry can be considered:

- No matter how precise a measurement is, the result obtained from the measurement cannot be true and is subject to error [18,38].

- Conclusions derived by an inductive process cannot be said to be true even if they are drawn out in many and various situations [25,38].

- To suggest a scientific hypothesis, an abductive method that borrows other explanations from other phenomena can be useful [39,40].

- Even if experimental results supporting the hypothesis are obtained, it cannot be concluded that the hypothesis is correct [41,42].

Regarding the above methodological beliefs, we, first, need to investigate how students think about or whether they agree with these beliefs. And it will be interesting if we investigate whether students' beliefs affect the inquiry process in the context of inquiry activities related to the above beliefs.

In fact, the methodological beliefs mentioned in the above are deeply related to the nature of science. Therefore, it can be inferred that the fact that methodological belief influences scientific inquiry activities implies that understanding the nature of science affects scientific inquiry. In this way, research on the influence of methodological beliefs in scientific inquiry can directly contribute to the study of how an understanding of the nature of science can affect scientific inquiry.

VI. CONCLUSION

The result of background knowledge affecting inquiry activity raises an interesting question. In other words, does the impact of background knowledge on inquiry activities help with inquiry activities? Or disturb it? This question is interesting because background knowledge is essential for the physical interpretation of the data, but it may interfere with new discoveries by treating unexpected aspects which are inconsistent with background knowledge as simple errors. Of course, in the p-v data used in this study, the background knowledge will not hinder new discoveries. However, we know well that new theories have emerged from inconsistencies with existing background theories. Furthermore, there are also many cases where students' prior misconceptions have distorted the interpretation of data.

In this study, we think that students could get a conclusion simply because of background knowledge, but at the same time, they had missed the possibility of further analysis and interpretation of the data due to their background knowledge. Therefore, it is necessary to have continuous concerns on the role and function of background knowledge on inquiry activities.

In addition, the fact that the students' methodological beliefs may influence scientific inquiry activities means that a sound understanding of the nature of scientific inquiry is important for more authentic scientific inquiry. Sound understanding of the nature of observation and measurement, the nature and role of scientific thinking (induction, deduction, and abduction), thinking strategies to suggest scientific hypotheses, and the logical structure of scientific explanations and predictions, and so on, plays an important role in performing scientific inquiry more authentically.

In this regard, this study shows the relationship between the nature of science and actual science inquiry activities. In addition, further research on how the various methodological beliefs influence the relevant inquiry activities will give us more meaningful and fruitful implications for teaching scientific inquiry in an authentic way.

ACKNOWLEDGEMENTS

This work was supported by the intramural research grant of Chungbuk National University in 2015.

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