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Argument-Based General Chemistry Laboratory Investigations for Pre-Service Science Teachers

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ABSTRACT
The purpose of this study was to examine the effects of argument-based general chemistry laboratory investigations on both understanding of chemistry concepts and a summary writing activity of pre-service science teachers. Argument-based general chemistry laboratory investigations were developed for five topics using the Science Writing Heuristic (SWH) approach. Twenty-three students in the treatment group were engaged in five argument-based general chemistry laboratory investigations over a semester. All the activities for the sixteen students in the control group were traditional general chemistry laboratory experiments. Data analyses indicated that there were significant differences between the treatment and the control groups in understanding of chemistry concepts and scores on the summary writing activity. The treatment group gained significantly higher scores in 'argumentation', 'understanding of science concepts', and 'rhetoric structure' components in the summary writing activity. An implication of this study is for pre-service science educators to continue to implement argumentation-based general chemistry laboratory investigations to help pre-service science teachers develop understanding of science concepts and summary writing.

KEYWORDS: argument-based inquiry, pre-service teachers

Resumen (Investigaciones basadas en la argumentación en el laboratorio de Química General para profesores en formación)
El propósito de este estudio es el de examinar los efectos de investigaciones basadas en argumentación sobre el laboratorio de Química General, tanto acerca de la comprensión de conceptos químicos, como acerca del resumen de la actividad escrita de profesores de ciencia en formación. Las investigaciones basadas en argumentación sobre el laboratorio de Química General fueron desarrolladas sobre cinco tópicos, empleando el enfoque de escritura heurística de la ciencia (SWH, por sus siglas en inglés). 23 estudiantes en el grupo bajo tratamiento fueron involucrados en cinco investigaciones basadas en argumentación sobre el laboratorio a lo largo de todo un semestre. Todas las actividades de 16 estudiantes del grupo de control fueron experimentos de laboratorio tradicionales. El análisis de los datos indicó que había diferencias significativas entre los grupos de tratamiento y control, tanto en el entendimiento de los conceptos químicos como en la calificación del resumen escrito. El grupo bajo tratamiento obtuvo calificaciones mucho mejores en los componentes de 'argumentación', de 'comprensión de conceptos científicos' y de 'estructura retórica' en los resúmenes de actividad escrita. Una implicación de este estudio dirigida a los educadores de profesores de ciencia en formación es continuar las investigaciones basadas en argumentación sobre el laboratorio de Química General con tal de ayudar a los profesores-estudiantes a desarrollar la comprensión de conceptos químicos y la actividad de escribir resúmenes.

Palabras clave: indagación basada en argumentación, profesores en formación

Introduction

The Korea National Science Curriculum encourages K-12 science teachers to implement inquiry-based activities in science classrooms (Korea Ministry of Education, 2007). Many studies have suggested that active use of language is critical to learning science, that is, students learn science while they are engaged in discussing their inquiry activities (Yore, Bisanz, & Hand, 2003). In this regard, there has been also strong support for engaging students in argumentation (Duschl, 1990; Kuhn, 1993). Despite this emphasis on argument-based inquiry investigations, science teachers are reluctant to implement inquiry-based teaching methods focusing on argumentation (Driver, Newton, & Osborne, 2000). It is not surprising then that inquiry-based science teaching is a big challenge for teachers who have been used to traditional ways of science teaching. In order to help pre-service science teachers develop self-efficacy regarding science inquiry, we recognized the importance of engaging these teachers in argument-

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based inquiry science investigations. In our study, we attempted to implement the Science Writing Heuristic (SWH) approach as an argument-based inquiry approach in general chemistry laboratory classes for Korean pre-service science teachers.

The Science Writing Heuristic (SWH) approach, which was proposed by Hand and Keys (1999), provides students with opportunities to engage students in argumentation within scientific inquiry. The SWH teacher template consists of a set of scaffolds which prompts students' reasoning thinking and supports meta-cognition activities (Keys *et al.*, 1999). Teachers in the SWH approach encourage students to communicate and negotiate their understanding about their science investigation as indicated in Table 1. The SWH template for students is a semi-structured writing form that scaffolds student reasoning thinking and facilitates metacognition about their laboratory investigations. Students are requested to generate questions, design procedure, collect data, organize and interpret data, propose claims, provide evidence, and reflect on the whole process of inquiry investigation. The SWH approach facilitates students' scientific reasoning and argumentation about their inquiry activities in both oral and written forms.

Several research studies in US setting have shown that the SWH approach is effective for improving college student conceptual understanding and cognitive engagement in general chemistry (Burke, Greenbowe, & Hand, 2006; Greenbowe, & Hand, 2005; Poock *et al.*, 2007; Rudd *et al.*, 2001; Rudd, Greenbowe, & Hand, 2007). Rudd *et al.* (2001) found that freshman chemistry students using the SWH approach produced better-written explanation of physical equilibrium than a control group. Rudd, Greenbowe, & Hand (2007) also found that the SWH approach help students enrolled in a general chemistry course for science majors to develop their conceptual understanding regarding equilibrium condition.

In providing Korea's pre-service science teachers with opportunities to be engaged in argument-based chemistry investigations using the SWH approach, we were keen to investigate the impacts of the SWH approach on pre-service science teachers' achievements with respect to chemistry concepts and summary writing. This study would provide important implications regarding pre-service science teacher education and their science conceptual development along with engaging in argument-based chemistry inquiry investigations.

Table 1. SWH Template for Teacher and Student.

Teacher's Template	Student's Template
Pre-Laboratory Activities: Teacher engages students to elicit pre-knowledge and gain understanding of the scientific context into which the laboratory is situated. Teacher may design pre-laboratory investigations such as brainstorming, developing questions about the topic, or expressing prior knowledge.	Questions: What are my questions?
Participation: Teacher encourages students to engage in an inquiry/laboratory investigation.	Test and Collect Data/Observation: What did I do? What did I see?
Negotiation I: Teacher guides students to think about the meaning of their data through journal writing.	Claims: What can I claim?
Negotiation II: Teacher encourages students to negotiate their understandings of the data with their peers. Students are encouraged to make knowledge claims to state explanations for their data.	Evidence: How do I know? Why am I making these claims?
Negotiation III: Teacher assists students to compare their ideas to textbook and on-line encyclopedia.	Reading: How do my ideas compare with others?
Negotiation IV: Teacher encourages students to communicate their current understandings of the investigation in a more polished form, i.e., writing a poem, letter or report, or creating a presentation or poster.	
Exploration: Teacher engages students to bring reflection to their understanding of the laboratory concepts.	Reflection: How have my ideas changed?

Methods

Participants

Participants of this study were thirty eight freshman students majoring in science education at a national university in Korea. All the students were enrolled in both a general chemistry lecture course and a related laboratory course during the first semester of their first year. They were in a single section of the general chemistry lecture course and were divided into two different laboratory sections. This study employed a quasi-experimental design with treatment and control groups. Twenty-two students from one laboratory section were assigned to the treatment group using the SWH approach and sixteen students from the other laboratory section were assigned to the control group using the traditional general chemistry laboratory teaching approach. The students in both treatment and control groups were assigned to work in groups of three. One instructor taught both the treatment and control groups for the general chemistry laboratory classes.

General Chemistry Laboratory Activities using the SWH Approach and the Traditional Approach

The students in the general chemistry laboratory class were expected to be involved in ten experiments during the course of the semester. Five general chemistry laboratory investigations with respect to 'acid and base,' 'antacid,' 'chromatograph,' 'enthalpy,' and 'chemical equilibrium' were developed using the SWH approach for treatment group. At the beginning of the semester, students in treatment group were introduced to the SWH approach for one and half hours. The students in treatment group were provided with the writing template provided by the SWH approach as follows: 1. Generating questions (What is my question? What is our group question? What is our class question?); 2. Procedure (How to answer the question?); 3. Observation/Data Collection (What did I observe? What did I learn from observation/data collection? Did I utilize any mathematical/chemical formula? Do I use graph or table if appropriate?); 4. Claim (What is my claim answering my/our class testable question?); 5. Evidence (What is evidence for my claim? What is my interpretation of the collected data, observation, graph, and/or table? Are there strong relationship between claim and evidence?); 6. Reading (What did I learn from other resources? How do I use the information from other resources to answer my testable question to support my claim?); 7. Reflection (How have my ideas changed? What is my following question? How is my learning form this investigation related to what I've known or examples in daily life?).

At the start of the laboratory session, students were provided the problem context related to the activity. Students were then required to write their own questions in their report and discussed their idea with their partners and decided group questions. Each group wrote their questions on the board and the whole class discussed and decided which questions were to be explored. Then, the students designed the procedure to test the question and collected data. As students analyzed the collected data, they were encouraged to propose claims as answers to the testable questions and to provide evidence supporting claims. The whole class was involved in sharing each group's claims and evidence and negotiating the meaning of the experiment. They were then given reading materials as reference resources and were requested to reflect on the whole inquiry investigations. Using the SWH writing template, students were engaged in negotiation of their ideas on questions, claims, and evidence throughout the inquiry investigation. The instructor actively guided students to help them understand what they were doing and encouraged them to be involved in discussions in their group and whole class settings. The students in the treatment group completed the other five activities using the traditional laboratory approach.

All the ten activities for control group were based on the traditional laboratory approach. The lab report format used for the control group included: 1) purpose, 2) procedure, 3) observation, 4) conclusion, and 5) discussion. In the traditional laboratory approach, the instructor provided students with detailed instructions regarding the purpose of the experiment, background, and experimental procedure. The students were requested to simply follow the procedure given, summarize data and results, and draw conclusions and discussion as they answered guiding questions given to them.

Data Collection and Analysis

Two pre-summary writing tests were implemented with both the treatment and control groups before the intervention of this study on the topics of 'acid rain' and 'reactivity of metal.' The Summary Writing Test (SWT) was based on the idea that writing is not simply to link together the concepts of the topic but also to persuade, or argue a point of view. Therefore, students' summary writing was scored with respect to students' building of the conceptual framework in the following four components: 'big idea,' 'science concept,' 'argumentation,' and 'rhetoric structure.' An analysis framework to evaluate the quality of the summary writing was developed in this study based on the framework by Hand *et al.* (2009). The scoring framework of the summary writing was developed and revised based on feedback from a professor and four doctoral students in science education. Two doctoral students scored ten summary writing samples chosen at random and discussed each item until the difference between two raters was no more than two points. Then one rater performed the scoring of all the students' summary writing pieces. One post-summary writing test was conducted after the implementation on the topic of 'acid and base.' In both summary writing tests, students were asked to write a letter to explain the topic to their younger brother taking chemistry course at the high school level.

A Chemistry Concept Test (CCT) was also implemented after the intervention. The Chemistry Concept Test (CCT) consisted of ten open-ended questions related to the concepts that the students explored in the five chemistry laboratory experiments on 'acid and base,' 'antacid,' 'chromatograph,' 'enthalpy,' and 'chemical equilibrium.' Content validity of the ten items of the CCT was examined and verified by a professor and four doctorate students in science education.

Data analyses were carried out using the Statistical Package for Social Science (SPSS) for Windows, Version 15.0.

Results

Summary Writing Test (SWT) Scores

Independent samples *t*-test indicated that there was no statistically significant difference between the treatment and the control groups in both two pre-summary writing tests as shown in Table 2. For the summary writing on acid rain, there was no significant difference in the SWT total score between the treatment group (M = 30.65, SD = 8.05) and the control group (M = 27.00, SD = 11.82; t (37) = 1.074, p = 0.293).

Table 2. *T-test on the Pre-Summary Writing Tests.*

Topics	Group	N	Mean	SD	*t*-value
Acid Rain	Treatment	23	30.65	8.05	1.074
	Control	16	27.00	11.82	
Reactivity of Metals	Treatment	23	23.00	6.53	0.575
	Control	16	21.63	8.41	

$^{*}\ p < 0.05$

Table 3. Sub-Component Scores of the Pre-Summary Writing Test (SWT)

		group	N	M	SD	*t*-value
Acid Rain	Big idea	Treatment	23	8.91	5.21	0.668
		Control	16	7.81	4.82	
	Science concept	Treatment	23	4.96	2.23	1.718
		Control	16	3.75	2.27	
	Argumentation	Treatment	23	8.30	2.32	1.331
		Control	16	6.94	3.86	
	Rhetoric structure	Treatment	23	8.52	3.15	0.019
		Control	16	8.50	3.97	
Reactivity of Metals	Big idea	Treatment	23	4.57	3.34	–0.895
		Control	16	5.63	4.03	
	Science concept	Treatment	23	2.70	1.40	0.280
		Control	16	2.56	1.55	
	Argumentation	Treatment	23	7.48	2.48	2.294*
		Control	16	5.50	2.88	
	Rhetoric structure	Treatment	23	8.17	2.48	–0.735
		Control	16	8.75	2.30	

*$p < 0.05$

There was also no significant difference in the SWT total score between the treatment group (M = 23.00, SD = 6.53) and the control group (M = 21.63, SD = 8.41; t (37) = 0.575, p = 0.569) for the summary writing on reactivity of metals.

As shown in Table 3, there was no significant difference in the sub-component scores of 'big idea,' 'science concept,' 'argumentation,' and 'rhetoric structure' in the acid rain summary writing between the treatment and the control groups ($p > 0.05$). In the reactivity of metals summary writing, there was no significant difference in the scores of 'big idea', 'science concept' and 'rhetoric structure' between the treatment and the control groups ($p > 0.05$). However, there was significant difference in the score of 'argumentation' between the two groups (t (37) = 2.294, $p < 0.05$).

Table 4 indicated that the treatment group gained higher total score of as measured by adjusted mean of the post-summary writing test (SWT). Each sub-component score of the post-SWT was also higher for the treatment group than the control group.

A one-way Analysis of Covariance (ANCOVA) model was conducted to determine significant differences in the post-SWT scores using the total score of pre-SWT as the covariate. There was significant difference in the adjusted mean score of total score between both the treatment and the control groups (F (1, 37) = 7.727, p = 0.009, η^2 = 0.177). Cohen's d index was also calculated to measure the magnitude of effect size of programs. The effect size measured by Cohen's index was large (Cohen's d = 1.0).

A one-way Analysis of Covariance (ANCOVA) model was conducted to determine significant differences in each sub-component score of the post-SWT using each component score of the pre-SWT as the covariate. There was no significant difference in the adjusted mean score of 'big Idea' between both the treatment and the control group (F (1, 37) = 0.061, p = .806, η^2 = 0.002). There was significant difference in the adjusted mean score of 'science concept' between both the treatment and the control group (F (1, 37) = 16.43, p = 0.000, η^2 = 0.313). The size of effect of the 'science concept' measured by the Cohen's d index was large (Cohen's d = 1.3). For 'argumentation' sub-component, there was significant difference in the adjusted mean score between both the treatment group and the control group (F (1, 37) = 7.026, $p < 0.05$, η^2 = 0.236). The size of effect of the 'argumentation' measured by the Cohen's d index was large (Cohen's d = 1.2). Also, the treatment group gained a significantly higher score than the control group (t (37) = 2.446, $p < 0.05$) in the 'rhetoric structure.' The size of effect of the both groups measured by the Cohen's d index was large (Cohen's d = 1.3).

Table 4. Adjusted Mean and Standard Deviation of the Post-Summary Writing Tests.

Sub-component		N	Post-SWT	
			Adj. M	SE
Treatment	Big idea	23	12.59	0.64
	Science concept		15.81	0.98
	Argumentation		10.00	0.77
	Rhetoric structure		8.44	0.55
	Total score		46.05	2.49
Control	Big idea	16	12.84	0.77
	Science concept		9.46	1.16
	Argumentation		5.93	0.93
	Rhetoric structure		6.24	0.66
	Total score		35.12	3.00

*$p < 0.05$

Chemistry Concepts Test (CCT)

T-test results indicated that the treatment group (M = 47.26, SD = 5.48) performed significantly better than the control group (M = 40.56, SD = 9.99; t (37) = 2.438, $p < 0.05$) as measured by the Chemistry Concepts Test CCT as shown in Table 5. The effect size of the both groups measured by the Cohen's d index was large (Cohen's d = 0.8).

Discussion

The results from this study show that the treatment groups were able to make significant gains in both their understanding of the chemistry concepts and their ability to writing about the chemistry concepts to different audiences. Importantly, this argument based approach appeared to help students gain a richer understanding of argumentation and how to present this argument based on the summary writing test

Table 5. *T*-test of the Chemistry Concept Test.

Group	N	Mean	SD	*t*-value	*p*
Treatment	23	47.26	5.48	2.438*	0.024
Control	16	40.56	9.99		

*$p < 0.05$

scores. This is important given that much of teacher preparation is focused on chemistry knowledge only, and does not deal with how to communicate this knowledge. The SWH approach used in this study appears to have been able to support both of these critical functions — understanding of the concepts and communicating these concepts.

The critical role of language in the SWH approach appears to have impacted on student learning. Students were required to be part of the learning process in negotiating publically their questions, claims and evidence as critical elements of the laboratory activities. The impact of the emphasis on language is noted by the treatment students' performance on the summary writing activity. Importantly these results match the gains in understanding achieved by the earlier studies conducted in the US on using the SWH approach for general chemistry laboratory courses.

In terms of pre-service teacher education we believe that there is an important implication arising from this study. Teachers need to experience argument-based inquiry approaches like the SWH approach if they are going to implement such approaches within their classrooms. A shift away from traditional approaches to inquiry is necessary if we are going to provide this group of students with the necessary experiences to be able to use argument-based inquiry in their classrooms. While this study represents a small group of students for one semester, we would suggest that an implication of this study would be for pre-service science teacher educators to implement an argument-based inquiry approach in order to help pre-service science teachers develop understanding of science concepts, argumentation, and rhetoric structure along with their authentic experiences of inquiry-based scientific investigations.

Pre-service science teachers' engagement in authentic inquiry investigations using the SWH approach can be also effective way to develop pedagogical content knowledge with respect to inquiry-based science teaching. Understanding the importance of science literacy in science education, pre-service science teacher education should promote their experience of authentic scientific inquiry which facilitates generating questions, proposing claims, supporting with evidence, and communicating using variety of means such as presenting in public, as provided by the SWH approach.

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