Argument Structure in the Science Writing Heuristic (SWH) Approach

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Abstract: The purpose of this study was to evaluate students' written arguments embedded in scientific inquiry investigations using the Science Writing Heuristic (SWH) approach. Argument components defined in this study are questions, claims, questions-claims relationship, evidence, claims-evidence relationship, multiple modal representations, and reflection. A set of criteria for evaluating each argument component was developed to evaluate writing samples of students from college freshman general chemistry laboratory classes. Results indicate that students produced, on average, moderate to powerful questions, claims, and evidence. They also constructed reasonable questions-claims relationship and claims-evidence relationship. Compared to other component scores, the average score for reflection was relatively low. Overall, the average Total Argument score was 21.4 out of a possible 36, that is, the quality of the written arguments using the SWH approach during a series of inquiry-based chemistry laboratory investigations was moderate to powerful. The findings of this study suggest that students, on average, developed reasonable scientific arguments generated as part of scientific inquiry. In other words, students are capable of putting together reasonable arguments as they participate in inquiry-based laboratory classrooms.

Key words: argument structure, scientific inquiry, written argument

I. Introduction

The importance of scientific inquiry has been highlighted in recent documents within science education (AAAS, 1993; National Research Council, 1996, 2000). According to the National Research Council (1996), "scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work (p.23)." The Benchmarks for Scientific Literacy describes scientific investigations as "the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence" (American Association for the Advancement of Science, 1993, p. 12). With respect to this, science teachers have tried to provide opportunities for students to experience hands on activities in science classrooms. As many science educators have argued, providing students with experiences in doing scientific laboratory activities is certainly a start but it is not enough for student learning science (Shymansky, Kyle, & Alport, 1983; Willett, Yamashita, & Anderson, 1983; Wise & Okey, 1983). Doing scientific inquiry should be much more than simply doing hands on activities. As emphasized by Lemke (1990), students should be provided with opportunities to "integrate writing, talking, and reasoning with other forms of actions such as making observation and measurement" (p.154). Students should be able to reflect on what they are doing while conducting a scientific inquiry and engaging in talking, reasoning, analyzing, writing, and sharing findings. Students learn science while they are engaged in discussing and negotiating about their investigations in both oral and written forms (Driver, Newton, & Osborne, 2000; Duschl, 1990; Kuhn, 1993). Several studies have highlighted the importance of language suggesting that it is a necessary part of constructing new understandings of scientific

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ideas, of accessing and comprehending established scientific ideas stored in various information sources, and of informing and persuading other scientists and the public about scientific ideas (Giere, 1991; Halliday, 1993; Lemke, 1990; Norris & Phillips, 2003; Yore, Bisanz, & Hand, 2003). A critical part of inquiry based science teaching and learning is student argumentation in both oral and written forms.

The recognition of the importance of argumentation in science has promoted efforts to identify and analyze student reasoning and argument construction. However, there have been few studies which have looked at student arguments produced in the context of an authentic scientific inquiry although it has been argued that scientific inquiry in classrooms should include opportunities for students to learn to develop evidence based arguments (NRC, 1996). With this respect, this study attempts to explore the quality of student arguments generated from inquiry based science investigations using the Science Writing Heuristic (SWH) approach (Keys, Hand, Prain, & Collins, 1999). This study examined the quality of the argument achieved by students in a college inquiry based general chemistry laboratory class using the SWH approach.

Ⅱ. Background

Argument Analysis

Going beyond simply recognizing the centrality of language to science, researchers have argued for the importance of arguments in scientific inquiries. This has led to considerable interest in argument structure (Kelly, Chen, & Prothero, 2000; Kuhn, 1993; Osborne, Erduran, & Simon, 2004; Sandoval & Millwood, 2005). Much of research studies on arguments are based on the work of Stephen Toulmin (1958). As presented in Table 1, Toulmin, Rieke, and Janik (1984) identified the four key components of an argument–claims, grounds, warrants, and backing. In addition, Toulmin identified two other features found in more complex arguments. “Qualifiers” specify the conditions under which the claim can be taken as true. “Rebuttals” specify the conditions when the claim will not be true.

Several research studies have tried to use Toulmin's (1958) argument model to assess student arguments. However, in many of these studies researchers or teachers provided the students with data and socio scientific topics. In other words, students were not involved in generating questions or collecting data, but were simply asked to discuss the given topics, interpret the provided data, and generate claims and evidence. One example of this, a study by Kelly, Chen, and Prothero (2000) utilized interactive CD ROMs providing geological data sets for students who were given the task of producing claims and evidence in written form. In the Knowledge Integration Environment (KIE)

Table 1
Components of General Pattern of Argument

Component	Questions to Answer	Definition of Component
Claim	What is my stance on the issue?	The destination of the argument. An assertion that one makes about a topic
Grounds	What information is the claim based on?	The facts or data on which the claim is founded
Warrants	How do I move from grounds to claim?	Reasons (rules, principles, etc.) that are supposed to justify the connections between the data and knowledge claim.
Backings	What other information contributes to the warrant?	Basic assumption that provide the justification for particular warrants.

Source: Toulmin *et al.*, 1984

debate projects of Bell and Linn (2000), students were provided with two theories about the propagation of light and asked to compare them. They were then asked to state their personal position on how far light goes, to evaluate and incorporate complex information found on the internet, and to develop evidence and construct their arguments using SenseMaker (software developed to support student writing). Similarly, Sandoval and Reiser (2004) used the software tool Explanation Constructor to support and scaffold students' arguments about natural selection. This software contains a set of explanation templates which provide students with guidance about the content of their explanations. It includes a facility for helping students to link data to specific claims in their explanations and provides students with necessary and sufficient evidentiary warrants (or backing) for specific claims. This kind of research, which examines how students use the provided data to generate and support claims, is meaningful in that it can help us to understand students' epistemological ideas about what the data show, what kinds of claims need evidence, which do not, and so on.

However, it is apparent that simply having students practice argument skills, i.e., producing claims and evidence is not the goal of teaching science. As argument is a central feature of authentic scientific inquiries, it becomes clear that argument structure should be examined in a context of scientific inquiry. In this respect, this study identifies argument structure embedded in scientific inquiry investigations using the Science Writing Heuristic (SWH) approach.

Science Writing Heuristic (SWH) Approach

The Science Writing Heuristic (SWH) approach was developed by Hand and Keys (1999) as a way to facilitate student learning from scientific inquiry through writing-to-learn strategies (Keys, Hand, Prain, & Collins, 1999; Hand & Prain, 2002).

The SWH approach includes two heuristic templates which are used as a structured teaching and learning tool and requires both teachers and students to be active and interactive in laboratory investigations (Burke, Greenbowe, & Hand, 2006). The SWH template for teachers, as shown in Table 2, consists of a set of scaffolds which prompts students' reasoning and supports meta-cognition. Using the SWH teacher template, teachers can design inquiry-based activities with emphasis on the social and personal negotiation of meaning.

Using the SWH approach, students are engaged in the whole process of scientific inquiry. The SWH template for students, as shown in Table 3, is a semi structured writing form that scaffolds student reasoning and facilitates meta cognition about their laboratory investigations (Hohenshell & Hand, 2006). The SWH template for students is designed to help them to construct scientific knowledge within a scientific inquiry. In the SWH approach, students are not told explicitly how to do the experiments; rather students are required to be more active in generating and answering questions. The SWH approach requires a much more epistemic role for students (Yore, Bisanz, & Hand, 2003). Students are encouraged to articulate their beginning questions about a topic, identify patterns in their collected data, construct claims based on the interpretation of data, support their claims with evidence, and reflect on their investigations. This is a very different approach to the traditional method of asking students to respond passively to the five sections of purpose, methods, observations, results, and conclusions.

Several research studies have also shown that the SWH approach is effective for improving student conceptual understanding and cognitive engagement in science. A study by Hand, Wallace, and Yang (2004) found that 7th grade students who used the SWH approach performed significantly better than control students on both lower order items and higher-order conceptual items in an end-of-unit test. A

Table 2
The SWH Template for Teachers

Phase	Description of Phase
Exploration	Teacher engages students to elicit pre-knowledge and gain understanding of the scientific context into which the laboratory is situated.
Pre-Laboratory Activities	Teacher may design pre-laboratory investigations such as brainstorming, developing questions about the topic, or expressing prior knowledge.
Participation	Teacher encourages students to engage in an inquiry/laboratory investigation.
Negotiation Phase I	Teacher guides students to think about the meaning of their data through journal writing.
Negotiation Phase 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.
Negotiation Phase Ⅲ	Teacher assists students to compare their ideas to textbook and on-line encyclopedia.
Negotiation Phase 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.

Table 3
The SWH Template for Students

Phase	Questions Related to Phase
Beginning Ideas	What are my questions?
Tests	What did I do?
Observations	What did I see?
Claims	What can I claim?
Evidence	How do I know? Why am I making these claims?
Reading	How do my ideas compare with others?
Reflection	How have my ideas changed?

recent study by Hohenshell and Hand (2006) found that 9th and 10th grade students using the SWH approach performed significantly better on conceptual questions than the students from a control group after experiencing a summary writing activity.

Writing as a Way of Doing Science

As stated by Wellington and Osborne (2001, p. 83), "learning to reason in science requires the ability to construct arguments that link evidence and empirical data to ideas and theories. Practical work alone is insufficient to create a bridge between observation and the ideas of science." They insist on the need for minds-on activity such as written discourse as well as hands on activity. Keys (1999) asserts that a unique feature of writing in scientific genres is the construction of new knowledge from scientific inquiry investigations, especially through the formation of meaningful inferences from data. Science writing also provides students with an opportunity to construct written arguments based on claims and evidence (Osborne, Erduran, & Simon, 2004). Wallace, Hand, and Prain (2004) also argue that "writing is one mode of "doing science, just as hands-on laboratory work, Internet research, reading, or oral discourse" (p. 2). They point out that, "science writing involves the use of reasoning skills to organize information, describe scientific phenomena, create knowledge claims, and formulate an argument; and thus it has potential for fostering content learning" (p. 1).

Research studies have demonstrated that the SWH approach provides students with such opportunities (Hand & Keys, 1999; Keys, 2000; Keys, Hand, Prain, & Collins, 1999; Wallace, 2004b). Keys, Hand, Prain, and Collins (1999) examined the characteristics of nineteen 8^{th} grade students' writings using the SWH approach. They reported that the use of the SWH approach enabled students to generate meaning from data, to make connections among procedures, data, evidence, and claims, and to be engaged in meta-cognition. They also indicated that the students improved in their ability to understand the nature of science from a vague understanding to a more complex, rich, and specific understanding. In a study of examining the students' thinking processes while they wrote laboratory reports using the SWH template, Keys (2000) found that nine of the sixteen students demonstrated scientific problem solving strategies, including producing hypotheses and evidence, examining patterns in the data, and making general knowledge claims. She also indicated the act of writing using the SWH template can stimulate science learning directly. Furthermore, Wallace (2004) examined how students utilize a variety of knowledge sources while engaged in writing using the SWH template. She found that three of the six students in her sample drew on their collected data/observations as their major source of understanding; one of the six students relied solely on textbook and teacher statements; and two students integrated their data/observations with canonical information found in the textbook and other reading sources. She noted that the students who bridged firsthand observations and authoritative text were able to construct rich and detailed explanations of scientific concepts.

Taken together, SWH template provides opportunities for students to think critically and to reason about the meaning of their laboratory data while also promoting the development of scientific concepts. The SWH approach provides students with opportunities to be engaged in social and personal negotiation on their inquiry-based scientific investigation. With respect to this, a writing sample produced by a student using the SWH approach is an argument about his/her inquiry investigation. In this regard, this study aimed to develop criteria for evaluating the quality of arguments produced by students using the SWH approach.

Ⅲ. Methods

A Set of Criteria to Analyze the Quality of Students' Written Arguments Using the SWH Approach

The impetus for this study was the need to develop a set of criteria to analyze the quality of students' written arguments as they use the Science Writing Heuristic (SWH) approach. By examining student writing samples, argument components were identified and a set of criteria for evaluating each argument component was developed and informed. In this study, science writing samples using the SWH approach were collected from fourteen students who were taking an inquiry-based general chemistry laboratory course at a large university located in the mid-west. They were required to complete and submit for each of ten laboratory investigations over the course of one semester. After thoroughly and repeatedly examining student writing samples, initial coding was assigned to each student writing samples. By combining the initial codes, some initial patterns were identified. By comparing the initial patterns in terms of their properties and dimensions, the patterns of student writing samples were identified. Using the identified patterns, criteria for analyzing each argument component were developed.

In previous research studies, the strength of the relationship between claims and evidence has been identified as a challenging and essential component of the student argument. While a claim is a central artifact of science and is at the base of all arguments, the presentation of evidence in relation to claims is particularly crucial to the development of a scientific argument (Bazerman, 1988). The view that science is a social process of knowledge construction (Taylor, 1996) leads to the recognition that it is not possible to ground a claim for truth in observation or data alone. Rather, claims have to be grounded in evidence which is framed conceptually (Driver, Newton, & Osborne, 2000; Newton, Driver, & Osborne, 1999). In other words, the effort to organize claims, evidence, and data into persuasive accounts is a central process of constructing a scientific argument (Osborne, 2002; Osborne, Erduran, & Simon, 2004; Sandoval & Millwood, 2005). An inability to utilize logical connectives, therefore, results in difficulties in understanding and communicating scientific ideas (Gardner, 1980). In this respect, the first attention by the researcher in this study was examining whether evidence provided by students was well connected to their claims or their evidence supported their claims. There were a few cases in which a student constructed a weak relationship between claims and evidence despite providing powerful evidence. On the other hand, even though evidence can support a claim in an appropriate way, the quality of evidence could be low. With this respect, the quality of evidence itself was identified as a separate component from the component of the relationship between claims and evidence. Some of the criteria are as follows: Is the suggested evidence well connected with their claims? Do students suggest evidence which support their claims?

How the students used multiple modal representations was also examined. While students interpret their data or observations, looking for patterns and relationships, they can represent their analysis of data in a variety of ways–using tables, graphs, diagrams, mathematical equations, or chemical equations as they mobilize evidence to defend their claims. As argued by Wu and Shah (2004), visualization plays a major role in science, in particular in chemistry. Sandoval and Millwood (2005) analyzed how students referred to data rhetorically to make their arguments and found that students' references to specific inscriptions in their arguments often failed to articulate how specific data related to particular claims. With this regard, the students' active use of multiple representations was concerned. Some of the criteria are as follows: Are students using the multiple modal representations? What kinds of multiple mode representations are students using?

Since students provide claims and evidence in order "to answer their questions," the quality of the questions generated by students could/should be part of putting together a high quality argument. It also appeared that the quality of the questions and the quality of the claims can be evaluated separately from the coordination between questions and claims. For example, students may begin with excellent questions and produce strong claims but there may be an inappropriate connection between their questions and claims; some students may begin with poor questions and make weak claims even though there is strong connection between the questions and claims. In addition to the quality of questions, the relationship between the posed questions and the generated claims was identified as an important component of the argument structure. This question-claims relationship has been rarely identified as important in other research studies. Some of the criteria are as follows: Are the proposed claims well connected with their questions? Do students propose claims which answer their questions?

The reflection component of the SWH template gives the students the opportunity to evaluate their reasoning expressed as a form of questions, procedure, data, claims, and evidence. Klein (2000) points out that "the search from text factor, including explicitly reviewing text to generate ideas and evaluating or revising, contributes significantly to learning during writing" (p. 342). Klein showed that the connection between cognitive and meta-cognitive strategies increased the students' learning from writing. In his study, students carried out science experiments concerning buoyancy or the balance beam, stated their explanations of the phenomena, and finally wrote about them in journal style notes while thinking aloud. Klein found that young writers who used forward search from text, forward search from experiments, and brainstorming as strategic problem solving efforts were able to improve their thinking skills despite the constraints of their relatively moderate writing abilities. As Klein points out, "the search from text factor, including explicitly reviewing text to generate ideas and evaluating or revising, contributes significantly to learning during writing" (p. 342). In this respect, searching for additional information and reviewing what has been stated are characteristics of those who have been learned from writing. With this respect, the reflection component, which is framed as a review of the previous sections and involves engagement in meta-cognition, was also identified as an important clue to the strength of a student argument.

In summary, there are seven argument components; questions, claims, questions-claims relationship, evidence, claims-evidence relationship, use of multiple modal representations, and reflection. This analytical framework was designed to evaluate student arguments according to the categories set out by the SWH template. Students, in other words, were expected to be able to distinguish their questions, claims, evidence, and reflection from each other and record each in the appropriate section of the science writing. The criteria for the analytical framework presented in Table 4. The analytical framework developed in this study captures the quality of student argument with respect to both conceptual adequacy and the coordination of each argument element (Sandoval & Millwood, 2005).

These scoring criteria were revised based on feedback from a professor and two other research assistants in science education. The professor had about twenty years experiences of research and teaching in science education, and the two graduate students had several years of experiences in science teaching and were involved in SWH research project for data analysis of students' writing samples and classroom videotapes. In a previous study, these analytical frameworks were examined as to whether they function as a way of evaluating the quality of arguments produced by the grade 5, 7, and 10 students (Choi, Notebaert, Diaz, & Hand, 2010).

Students

Students who participated in this study were taking an inquiry based general chemistry laboratory course at a large midwestern state university. Students were required to enroll in both a lecture course and a related laboratory course for general chemistry. The student writings samples analyzed in this study were collected from fourteen freshman students. All fourteen students participating were recruited from a single section of the general chemistry

Table 4
Criteria to Evaluate Each Argument Component

Each Argument Component	A Set of Criteria
Questions	• Are there multiple questions? • Are they open- or closed?ended questions? • Are the questions testable (scientific)? • Are the questions answerable after carrying out an experiment?
Claims	• Do students tell what they found out? • Are the claims based on students' collected data/observation? • Are the claims accurate and adequate?
Questions-Claims Relationship	• Are questions and claims strongly connected? • Do the questions and claims fit well together? • Do students propose claims for all the questions? • Do students propose claims for the questions that they did not generate?
Evidence	• Does evidence explain students' claims? • Does the evidence come from interpretation of students' data/observation? • Is evidence valid, accurate, reliable, or strong?
Claims-Evidence Relationship	• Does the evidence support their claims? • Do the claims and evidence fit well together? • Do students suggest evidence for all the claims that they proposed? • Do students suggest evidence that is not related with their claims?
Use of Multiple Modal Representations	• How many multiple-mode representations are students using for their evidence? • Do students use multiple mode representations to support claims?
Reflection	• Do students recognize what new things they have to think about if their ideas have changed? • Do students understand how their investigations tie into concepts about what they have learned in class? • Do students refer to some real life application to make a connection with their laboratory work? • Do students reflect how the evidence did or did not support their claims? • Do students spot errors that could be corrected? • Do students have new test questions?

laboratory course.

Students' Writings

All the student writing samples were collected over the course of one semester. Participant students completed and submitted science writings for each of ten laboratory investigations. In total, the 140 science writing samples from 14 students were collected. The topics of the laboratory investigations are shown in Table 5.

As a function of the laboratory work, students used the writing template provided by the Science Writing Heuristic (SWH) approach. They were also provided a writing model using the SWH template as concrete examples. As described in Table 3, students using the SWH template start with the testable beginning questions. Students then address any relevant general safety concerns about a particular substance or procedure and describe the procedures needed to perform their experiments. As students perform their experiment, they are

Table 5
The Topics of the Laboratory Investigations

Lab	Topics for Year 1
1	Acids, Bases and the Preparation of a Salt
2	The Empirical Formula of an Oxide of Copper
3	Acid, bases, and their reactions
4	Calorimetry Investigations
5	The Heat of Formation of Magnesium Oxide
6	Thermodynamic Open Inquiry Lab
7	Determining the Rate Law for a Reaction
8	The Effect of Catalysts on the Rate of Decomposition of H_2O_2
9	Kinetics Open Inquiry Lab
10	Gas-Phase Chemical Reactions

required to provide relevant qualitative observations, quantitative data, necessary calculations, and balanced equations. Students also provide a properly labeled graph that reflects the collected data when appropriate. Then, students propose claims to answer their beginning questions. And they support their claims with evidence based on their interpretation of their data. Students reflect on their laboratory investigations; they identify and explain sources of error and assumptions made during the experiment; explain how their ideas have changed; consider what new things they have to think about after doing the lab; explain how their work ties into concepts that have been learned in class; and refer to the text, class notes, or some real life applications to make a connection with the laboratory work.

Scoring Students' Writing Samples

The student writing samples were evaluated for the quality of the written arguments produced. Each argument component was scored on a scale of one to five. For example, a score of five points for the evidence component means that the student constructed very powerful evidence which was credible, reliable, and came from an interpretation of the data. On the other hand, a score of one point for the evidence component means that the student constructed very weak evidence which did not appear to have any connection to the data and seemed very inaccurate. A score of three points for the evidence component suggests that the student constructed moderate quality evidence using the textbook and with a limited interpretation or explanation of the data.

The Total Argument score was calculated as the sum of the seven component scores and the additional point for embedding. One additional point was given for embedding of multiple modal representations. Embedding means that the multiple-modal representations were contextualized and explained in their evidence section. The maximum possible points that a student could receive for the Total Argument score were 36. The scores between 0 and 7 points indicate very weak arguments, and the scores between 7 and 14 points correspond to weak arguments. The scores between 14 and 21 points correspond to moderate arguments, and the scores between 21 to 28 points were considered powerful argument. The scores between 28 to 35 correspond very powerful arguments.

Intra class correlation (ICC) was used to measure the inter-rater reliability (Shrout & Fleiss, 1979) of scoring students' writing samples using the scoring criteria by two graders. The intra-class correlation coefficient was 0.97 for the Total Argument score.

Ⅳ. Results

The average score for each component out of 5 was as follows: 3.7 for questions; 3.3 for claims; 3.2 for the questions claims relationship (QC relationship); 3.2 for evidence; 3.2 for the claims evidence relationship (CE relationship); 1.8 for multiple modal representations; 2.4 for reflection. As shown in Figure 1, the scores for questions were relatively high; the scores for reflection were low.

The average score for the questions component fell between 3 and 4 (moderate and high) levels. What this score means is that the students on average generated high quality questions which were significant and testable and captured the essence of the laboratory investigation. They were either multiple closed-ended questions or at least one open-ended question.

The average score for claims component fell between 3 and 4 (moderate and high) levels. Students on average appeared to propose single or multiple claims, which were based on their experimental data and were appropriate and matched the essence of the laboratory investigation.

The average score for the questions-claims relationship (QC relationship) component fell between 3 and 4 (moderate and strong connection) levels. What this score means is that the students' proposed claims appeared to be apparent in answering questions even though students develop claims only for some of their questions. Alternatively, the claims appeared to focus on all the questions but to be loosely connected to the questions.

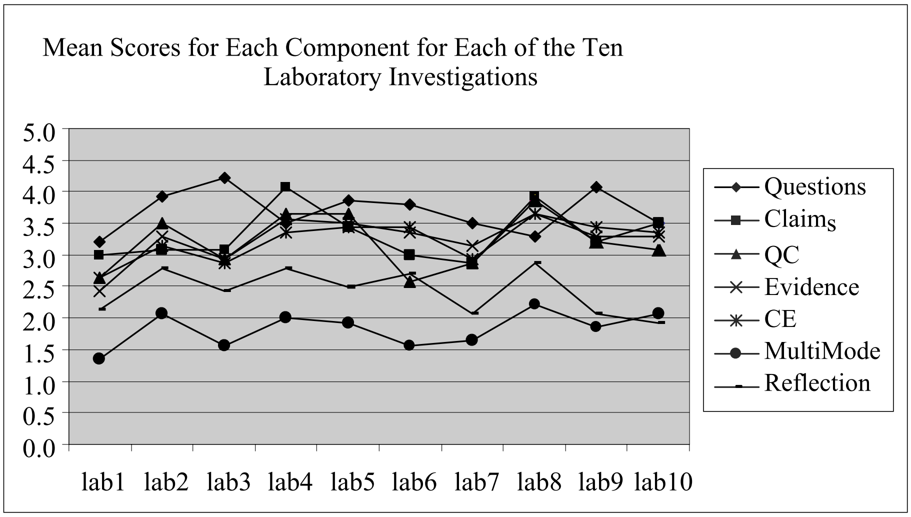
The average score for the evidence component fell between 3 and 4 (moderate and powerful) levels. This means that students provided a moderate quality of evidence from data and textbook with a little interpretation, which may be accurate and valid.

The average score for the claims-evidence relationship (CE relationship) component fell between 3 and 4 (moderate and strong) levels. This means that students supported claims with reasonable evidence. The proposed claims were supported by the patterns or relationships that emerged from student own collected data. The average score for the multiple mode representations component was 1.8. Students on average used 1.8 kinds of multiple mode representations, which could be text and one of other mode representations-graph, tables, math equations, or chemical equations.

The average score for the reflection component fell between 2 and 3 levels. This means that students weakly or moderately explained why their ideas have changed or did not change. The connection of their investigation to concepts and the identifying errors in reflection were weak, with only a few cases where new scientific questions were posed.

The Total Argument score in each laboratory investigation was generated from the sum of the seven component scores. Figure 2 also indicates the mean Total Argument scores in each of the ten laboratory investigations. The average Total Argument score was 21.4 out of a possible 36.

In summary, students produced, on average, moderate to powerful questions, claims, and evidence. They also constructed reasonable questions-claims relationship and claims-evidence relationship. Compared to other component scores, the average score for reflection was relatively low. Overall, the quality of the written arguments using the SWH approach during a series of inquiry based chemistry laboratory investigations was “moderate” to “powerful.”



QC: Questions-Claims Relationship
CE: Claims-Evidence Relationship

Fig. 1 *The Mean Scores for Each Component in Each of the Ten Laboratory investigations*

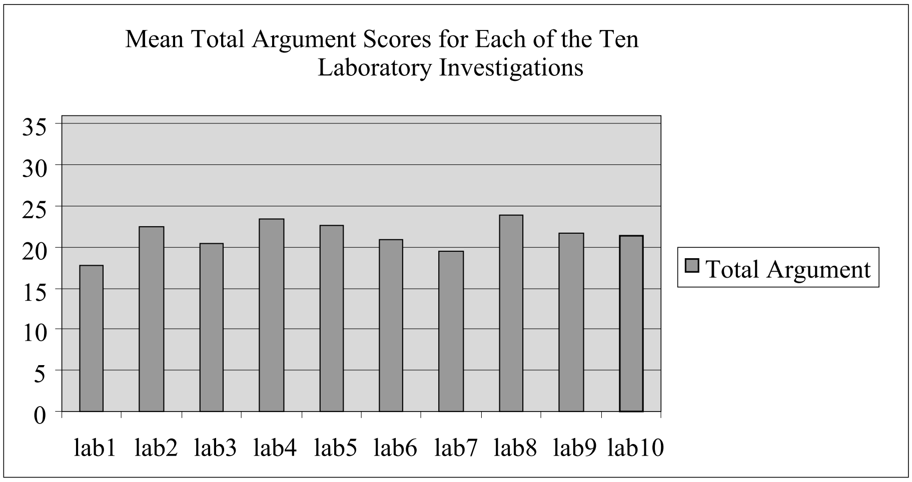


Fig. 2 *The Mean Total Argument Scores in Each of the Ten Laboratory Investigations*

Ⅴ. Discussion

Previous studies which have looked at student arguments in science classrooms have focused on the use of evidence and the connections made among data, claims, and evidence (Driver, Newton, & Osborne, 2000; Kelly & Takao, 2002; Newton, Driver, & Osborne, 1999). In these studies the researcher provided the data to be interpreted and explained by the students. From this, the researchers were able to draw some conclusions about the way students structure arguments, generate claims, and find supporting evidence. This is one way to teach the skills of proposing claims and providing evidence. Kuhn (1993) argues that many educational programs designed to teach thinking skills focus on teaching students about reasoning skills rather than actually engaging them in the practice of reasoning skills. She indicated the importance of authentic scientific inquiry to engage students in the practice of reasoning skills and to improve the coordination of explanations with data. But there have been few studies which have looked at arguments constructed by students as they participate in an authentic scientific inquiry and generate their own questions and data.

This study is therefore unique, in that the written arguments analyzed were produced by students in the context of scientific inquiry. As Osborne, Erduran, & Simon (2004) noted, initiating argument *in a scientific context* is harder and more demanding for students and teachers. Using the Science Writing Heuristic (SWH) approach, however, the students generated questions, designed the procedure, collected data, analyzed and organized data, proposed claims, provided evidence, and reflected on their whole inquiry. By the end of this, the students, on average, produced reasonable arguments. The results suggest that students can produce a quality argument with the support of the writing structure provided by the SWH approach. The findings of this study provide strong support for the position that student arguments should/could be part of an inquiry-based investigation in science classrooms.

In the traditional approach to teaching science, students conduct experiments following directions provided by teachers or textbooks and then write a report documenting their purpose, methods, observations, results, and conclusions. These traditional teaching methods have assumed that students simply need to master scientific concepts or learn a body of knowledge and that following directions in the laboratory experiments enhance their learning. Making arguments has been thought of as something only done by experts to advance knowledge at the frontiers of science, and not something that students should do or could do. Science teachers are often not convinced that student centered teaching and learning, which advocate allowing students to design and conduct their own investigations and make arguments about their findings, actually work. But, the analyses of the student arguments in this study show that students participating in inquiry-based laboratory investigations and using the Science Writing Heuristic (SWH) approach are capable of constructing arguments. As Keys (1999) asserted, students involved in an authentic scientific inquiry take personal ownership of their arguments, as they are writing to express their own ideas. When students participate in their own investigations and have the opportunity to tell others about its meaning, they are able to communicate about it with their own voice. In contrast to the situation in which students are provided with data generated elsewhere, students who conduct their own investigations can interpret their own data based on a contextualized understanding of the investigation and are better able to construct written expressions which link their data with their claims and evidence. This study implies that science teachers should provide students with more opportunities to construct argument embedded in inquiry-based scientific investigations to improve students' ability to construct argument in science.

The findings of this study also indicated that the level of reflection was, on average, much lower than "moderate". The average reflection score was much lower than the scores for all other components. The results indicated that students clearly found it difficult to reflect on their arguments and laboratory investigations. The lower reflection scores found in this study suggests that reflection continues to be a weak area for most students. But, it has the most potential to move them to a more sophisticated level of reasoning. Meta-cognition refers to an epistemological perspective of thinking about one's own thinking as the individual is thinking to improve his or her thinking (Yore and Treagust, 2006). Successful meta-cognition, in which a student monitors his or her own understanding or new knowledge integration, supports student conceptual growth. The reflection in the SWH approach provides students an opportunity to oversee their reasoning based on their own laboratory investigations. Students explain why their ideas have changed or did not change; identify errors of their experiments; make connections of their investigation to concepts; pose new scientific questions. In this sense, the reflection section is a place to overview their own reasoning and provides scaffolds for the students' critical thinking process. In this respect, understanding the role and benefits of reflection using writing template provided by the SWH approach teachers should facilitate the reflection process.

References

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

Bazerman, C. (1988). *Shaping written knowledge: The genre and activity of the experimental article in science*. University of Wisconsin Press, Madison, WI.

Bell, P. & Linn, M. C. (2000). Scientific arguments as learning artifacts: Designing for learning from the web with KIE. *International Journal of Science Education*, 22, 797-817.

Burke, K. A., Greenbowe, T. J. & Hand, B. M. (2006). Implementing the Science Writing Heuristic in the chemistry laboratory. *Journal of Chemical Education*. 83(7), 1032-1038.

Choi, A., Notebaert, A., Diaz, J., & Hand, B. (2010). Examining Arguments Generated by Year 5, 7, and 10 Students in Science Classrooms. *Research in Science Education*. 40(2), 149-169.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, 84, 287-312.

Duschl, R. A. (1990). *Restructuring science education: The importance of theories and their development*. Teacher's College Press, New York.

Gardner, P. L. (1980). The identification of specific difficulties with logical connectives in science among secondary school students. *Journal of Research in Science Teaching*, 17(3), 223-229.

Giere, R. N. (1991). *Understanding scientific reasoning* (3rd ed.). Fort Worth, TX: Holt, Rinehart & Winston.

Halliday, M. A. K., & Martin, J. R. (1993). *Writing science: Literacy and discursive power*. Pittsburgh, PA: University of Pittsburgh Press.

Hand, B., & Keys, C. W. (1999). Inquiry Investigation: A new approach to laboratory reports. *The Science Teacher*, 66(4), 27-29.

Hand, B., & Prain, V. (2002). Teachers implementing writing to learn strategies in junior secondary science: A case study. *Science Education*, 86(6), 737-755.

Hand, B., Wallace, C. W., & Yang, E. (2004). Using a Science Writing Heuristic to enhance learning outcomes from laboratory activities in seventh grad science: quantitative and qualitative aspects. *International Journal of Science Education*, 26(2), 131-149.

Hohenshell, L. M., & Hand, B. (2006). Writing to learn strategies in secondary school cell biology: A mixed method study. *International Journal of Science Education*, 28(2-3), 261-289.

Keys, C. W. (1999b). Revitalizing instruction in scientific genres: Connecting knowledge production with writing to learn in science, *Science Education*, 83, 115-130.

Keys, C. W. (2000). Investigating the thinking processes of eighth grade writers during the composition of a scientific laboratory report. *Journal of Research in Science Teaching*, 37(7), 676-690.

Keys, C. W., Hand, B., Prain, V., & Collins, S. (1999). Using the Science Writing Huerisitic as a tool for learning from laboratory investigations in secondary science. *Journal of Research in Science Teaching*, 36(10), 1065-1084.

Kelly, G. J., Chen, C., & Prothero, W. (2000). The epistemological framing of a discipline: Writing science in university oceanography. *Journal of Research in Science Teaching*, 37, 691-718.

Kelly, G. J. & Takao, A. (2002). Epistemic levels in argument: an analysis of university oceanography students' use of evidence in writing. *Science Education*, 86, 314–342.

Klein, P. (2000). Elementary students' strategies for writing to learn in science. *Cognition and Instruction*, 18(3), 317–348.

Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education*, 77, 319–337.

Lemke, J. L. (1990). *Talking science: language, learning, and values*. Norwood, NJ: Ablex.

National Research Council (NRC). (1996). *National science education standards*. Washington, D.C.: National Academy Press.

National Research Council (NRC). (2000). *Inquiry and the national science education standards*. Washington, D. C.: National Academy Press.

Newton, P., Driver. R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education*, 21(5), 553–576.

Norris, S. P., and Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, 87, 224–240.

Osborne, J. (2002). Science without literacy: A ship without a sail? *Cambridge Journal of Education*, 32(2), 203–218.

Osborne, J., Erduran, S., and Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, 41(10), 994–1020.

Sandoval, W. A., & Millwood. K. A. (2005) The quality of students' use of evidence in written scientific explanation. *Cognition and Instruction*, 23(1), 23–55.

Sandoval, W. A. & Reiser, B. J. (2004). Explanation driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry, *Science Education*, 88, 345–372.

Shymansky, J. A., Kyle, W. C., Jr., & Alport, J. M. (1983). The effects of new science curricula on student performance. *Journal of Research in Science Teaching*, 20, 387–404.

Taylor, C. (1996). *Defining science*. Madison, WI: University of Wisconsin Press.

Toulmin, S. (1958). *The uses of argument*. Cambridge: Cambridge University Press.

Toulmin, S., Rieke, R., & Janik, A. (1984). *An introduction to reasoning* (2nd Ed.) New York: Macmillan.

Wallace, C. S. (2004). An illumination of the roles of hands on activities, discussion, text reading, and writing in constructing biology knowledge in seventh grade, *School Science and Mathematics*, 104(2), 70–78.

Wallace, C. S., Hand, B., & Prain, V. (2004). Introduction: Does writing promote learning in science? In C. S. Wallace, B. Hand, & V. Prain (Eds.), *Writing and learning in the science classroom* (pp.1–8). Dordrecht, The Netherlands: Kluwer Academic Press.

Wellington, J., & Osborne, J. (2001). *Language and literacy in science education*. Philadelphia, PA: Open University Press.

Willett, J. B., Yamashita, J. M., & Anderson, R. D. (1983). A meta analysis of instructional systems applied in science teaching. *Journal of Research in Science Teaching*, 20, 405–417.

Wise, K. C., & Okey, J. C. (1983). A meta analysis of the effects of various science teaching strategies on achievement. *Journal of Research in Science Teaching*, 20, 419–435.

Wu, H., & Shah, P. (2004). Exploring visuospatial thinking in chemistry learning. *Science Education*, 88, 465–492.

Yore, L. D., Bisanz, G. L., & Hand, B. M. (2003). Examining the literacy component of science literacy: 25 years of language arts and science research. *International Journal of Science Education*, 25(6), 689–725.

Yore, L. D & Treagust, D. F. (2006). Current realities and future possibilities: Language and science literacy empowering research and informing instruction. *International Journal of Science Education*, 28, 291–314.