

AN EXPLORATORY STUDY OF STUDENTS' CONCEPTUAL UNDERSTANDING OF ENERGY CYCLE IN THERMOCHEMISTRY THROUGH ARGUMENT-BASED INQUIRY INSTRUCTIONAL STRATEGY (ABIIS) LABORATORY

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ABSTRACT

This study explores how laboratory activity with the argumentative approach could promote students' conceptual understanding in the Hess' law energy cycle through laboratory work. Laboratory work with an argument-based inquiry instructional strategy was set up to 15 pre-university students from one of the Form 6 Centre at the West Coast Division of Sabah, Malaysia. The laboratory work consists of a guided inquiry-based instruction with an argumentative approach in the topic of thermochemistry. The students' understanding of the energy processes was analyzed with a qualitative method using a semi-structured interview and triangulated with conversation analysis. The data collected from students' conversation during the activity was then triangulated with reflective writing at the end of the laboratory lesson. The study shows the students' prior knowledge and argumentation discourse significantly influences the development of conceptual understanding. This study emphasizes argument-based inquiry (ABIIS) in laboratory work to enhance their conceptual knowledge in the laboratory.

Keywords: Argumentative discourse, Conceptual understanding, Laboratory work

1. Introduction

Students need to know how to argue to learn science. Argumentation allows them to talk about an issue and gain a clear understanding of the new information. Argumentation is a discursive social process that happens when speakers question, support, and criticize each other's ideas to deal with debatable issues (Larraín, 2017). Learning to argue is an essential way of thinking that makes conceptual change possible and is crucial for solving problems (Jonassen & Kim, 2010). It is considered to show the potential for knowledge construction (Asterhan, 2018).

In Malaysia, the Science Curriculum Standards for primary and secondary schools emphasize high order thinking skills among students (Malaysia Education Blueprint, 2013) who indirectly introduce arguing abilities through class discussions and provide opinions based on authentic and open-minded grounds to accept new ideas. Scientific arguments should be taught so that students understand the significance of their conversations (Hanri, Arshad, & Surif, 2017). Students practice by asking questions and responding scientifically. This makes the students active in the science community, self-confident and successful in learning compared to just as passive learners (Heng & Surif, 2013).

Conceptual theory, such as Hess's law Energy Cycle in thermochemistry, is one of the most critical science concepts in chemistry. Science students should master it clearly and thoroughly. Hess's Law concept in thermochemistry is studied in the laboratory work and continuously stressed in the STPM examination. However, the annual report on STPM analysis provided by the Malaysian Examination Council (MEC) shows that the students do not clearly understand the concept of Hess's law. It has reported the students' difficulties in describing

thermochemistry concepts specific to Hess's law related to the energy cycle processes. Below are some of the comments.

Question 16. In part (a), most candidates were unable to define Hess' law completely. Many candidates did not write heat change or enthalpy change to define Hess' law (Majlis Peperiksaan Malaysia, 2016).

Question 16. Part (d) ... Many of the candidates were unable to draw a complete enthalpy cycle, and the equation in the cycle was not balanced (Majlis Peperiksaan Malaysia, 2016).

As a result, it discovered that even though the current STPM chemistry laboratory work has included the Hess' law concept of thermodynamics in the syllabus, it does not encourage the students' understanding of the topic. This problem was mentioned by Abrahams & Millar (2008) and Harrison (2016) as they observed that laboratory work is less successful in engaging the students with scientific ideas to direct their practices and interpreting the data they collected. There has been increased interest in alternative laboratory instruction styles such as inquiry-based approaches (Domin, 1999) that are conducive to chemistry teaching in the laboratory environment (Gormally, Brickman, Hallar, & Armstrong, 2011; Hunnicutt, Grushow, & Whitnell, 2015; Kodani, Fukuda, Tsuboi, & Koga, 2019). According to researchers, a laboratory learning program in which students explore chemical principles can be more successful than introducing them directly. At the moment, the emphasis of the scientific inquiry has changed from the assumption that research requires just discovery and experimentation to scientific argumentation based on facts and excellent results (Hanri et al., 2017), which are essential skills for future generations. Therefore, Form Six students' exposure to good scientific arguments during their laboratory activities can help develop their conceptual learning through consideration of their ideas in argumentative discourse (Nussbaum, Sinatra, & Poliquin, 2008). However, Malaysia's education system is still based on examinations (Academy of Science Malaysia, 2012; Heng Lee ling & Johari Surif, 2013; Ping & Osman, 2019) and, instead, make the education system more teacher-centred. Hence, the studies on the argumentative approach to promoting the conceptual understanding of Form Six students in STPM chemistry are relatively new. There has been limited research at the pre-university level, which is not less important as it helps students move to universities with more open curricula.

Therefore, this study explores the practice of an instructional intervention incorporated in the traditional laboratory course with existing Malaysian pre-university STPM Chemistry curricula by embedding the argumentation method in inquiry-oriented activities. The redesigned laboratory instructions that embed argumentation in this study is called Argument-Based Inquiry instructional strategy (ABIIS). It is designed to promote understanding of theoretical concepts through participating in the practices of science.

2. Literature Review

2.1. Social Constructivist Theory

This study effort to help students understand Hess's law conceptual knowledge through the argumentation approach is grounded in the social constructivist theory of learning by Lev Vygotsky (1978), a Russian psychologist. He explained that oral language to have two principle functions: communication and psychological tools (Wells, 1999; Shabani, Khatib, & Ebadi,

2010). He believed that the use of language with others transforms the way people think because, through language, people not only communicate but also collaborate psychologically. Vygotsky brings up communication as a tool for knowledge growth (Wells, 1999). Psychology reflects on one's activity and creates a possibility to develop inner speech, the speech oriented to oneself (Larraín, 2017). The inner speech will organize thoughts by doing reasoning, planning, and validating one's action (Muller Mirza, Perret-Clermont, Tartas, & Iannaccone, 2009). Peer argumentation promotes the development of both argumentative and disciplinary content knowledge (Asterhan & Schwarz, 2007). Asterhan (2018) suggested that the argumentative discourse should be issue-driven as its' concern is sense-making rather than persuasion.

According to Vygotsky (1978), a person's cognitive development has two levels: actual and potential. He explained that the level of real development is the person's ability to solve problems independently. The level of potential development is where the person is guided by a competent adult or more able peers. The distance between these two levels is the zone of proximal development (ZPD). ZPD is dependent on social interaction where the structures assist an adult, such as a teacher or competent peer, to go beyond what can be accomplished by the students themselves. The assistance in ZPD is referred to as scaffolding to help students achieve a higher understanding of managing difficult tasks within their ZPD (Reigosa & Jiménez-Aleixandre, 2007). Therefore, the education conceived in the school laboratory is a ZPD-oriented scaffolding that could be preferred through open problem-solving activities, which helps foster the requisite peer argumentation (Reigosa & Jiménez-Aleixandre, 2007).

2.2. Learning Science through Laboratory Work

Since the 1960s, the laboratory's unique nature as a tool for learning and teaching science has made it the focus of numerous research studies and reviews (Lunetta, Clough, & Hofstein, 2005). The teacher-centred style, or also referred to as traditional instruction, is typical for chemistry classes where students follow a prescribed experimental procedure over a set time. Students are first taught chemistry definitions, basic concepts and principles, and this is accompanied by laboratory work that supports the principles and theories. Such laboratory classes are designed to supplement lecture materials, and provide practical experiences for students, invaluable in their future careers as chemists. This approach is concluded in Figure 2.1.

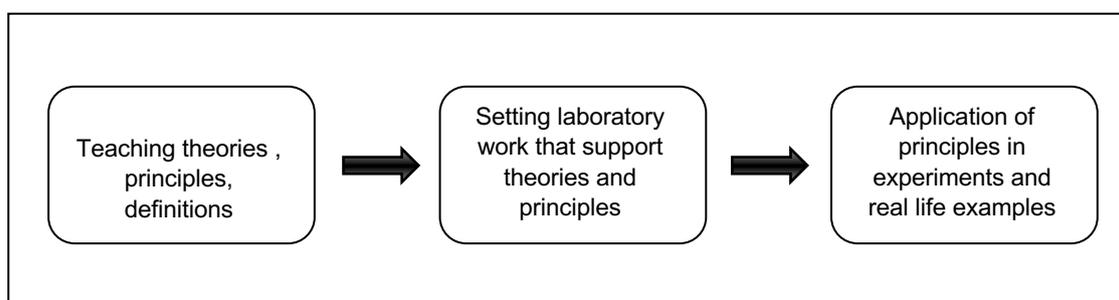


Figure 2.1: Traditional Approach in Teaching Chemistry (Gabel, 1999; Sirhan, 2007; Smithenry, 2010; Ibrahim, 2012)

Gabel (1999) stated that this approach is not necessarily the best way to organize the content for lessons. He mentioned that impairing the learning with its laboratory activities and applications produces knowledge that is much less used. As a result of this approach, students perceive that chemistry knowledge is no more than abstracts concepts, symbols and chemical equations.

The prescriptive nature of the laboratory instruction limits the possibility for students to relate and develop their content-specific knowledge (McGarvey, 2016); hence the students are uncertain of the aims of laboratory work and hesitant of what the outcomes mean or how they are applied to the theory provided in the lecture program. Furthermore, the instruction gives less opportunity for creativity as it is often about verification of a known quantity or testing of a theory that has been discussed in the lectures. These bring the struggle in producing students with critical thinking who involve with high-order intellectual activity within science knowledge in laboratory work (Kirschner, Sweller, & Clark, 2006; Kirschner, Sweller, Kirschner, & Zambrano, 2018) as though laboratory work to conceptual learning takes place in a different domain (Harrison, 2016).

2.3. Argument-Based Inquiry Instructional Strategy (ABIIS)

The Argument-Based Inquiry Instructional Strategy (ABIIS) is a laboratory instruction, compatible with current STPM Chemistry Coursework. It can be conducted in traditional instruction using constructivist writing inspired by (Van Duzor, 2016) to relate theory with laboratory practice. The instructional approach gives students opportunities to engage in argumentative discourse for the social construction of scientific ideas and improve their understanding of the scientific concepts. The argumentative session in ABIIS is inspired by the Argument-Driven Inquiry model of instruction (Sampson & Gleim, 2009).

ABIIS has no large scale of modification as it is integrated with the current STPM Chemistry Coursework syllabus, unlike with other new instructional strategies, such as the latest studies done by Ping & Osman (2019) on Biology laboratory instruction. ABIIS instruction in promoting students to work in pairs. That is because a partner's existence encourages reflection and appreciation of one's values (Larraín, 2017).

ABIIS introduces a new instructional strategy in chemistry practical laboratory work to students and teachers of pre-university (Form 6) level. It addresses the issues in traditional laboratory approaches by implementing effective teaching activities in the chemistry laboratory. The instructional strategy consists of six task components (Table 2.1), and each task is equally significant to achieve the proposed outcome of connecting theory and practice. It is primarily to encourage laboratory lessons for students to understand the theoretical principles by dealing with argumentation and process-based writing in science practices.

Table 1: Task Components Performed by Students

Phase	Task Component	ABIIS	STPM Chemistry Coursework
1	Identification of Task and Design Method	+	+
			(only if it is guided inquiry laboratory instruction)
2	Data Collection and Analysis	+	+
	Develop Preliminary Argument	+	-

Argumentation Session	+	-
Reflective Discussion	+	-
Laboratory Report	+	+

3. Objectives

This study's focus was to explore how laboratory activity with the argumentation approach; ABIIS could promote students' conceptual understanding in the Hess' law energy cycle through laboratory work.

4. Methodology

4.1. Participants and Tasks

Data were collected in a classroom of 12 students from one of the Form 6 Centre at the West Coast Division of Sabah, Malaysia. These participants were selected with particular categories by the researcher; 18 years old of participants and have similar cognitive level as they had just sat for their first-semester examination. A chemistry laboratory specifically in the course of thermochemistry, was used in this study. The teacher prepared the participants into small groups, and they were required to carry out tests to deduce the amount of energy released of a chemical reaction.

The teacher gave prompted questions to the students that were planned to act as scaffolds to hint students on the tests' reactions. Table 1 presents the task performed by each group. Although the teacher expected the students to work in pairs for all the tasks given (Table 1), there were some parts that they did not reach complete or appropriate solutions, as discussed later.

4.2. Data Collection and Analysis

This is a small-scale study with a qualitative method. The primary data sources were participants' interviews, audio recordings of the teacher and participants' discourse, and reflective report at the end of the laboratory activity. Structured interviews have been done with the participants a week after the laboratory activity was done. During the meeting, the participants had to answer how they created the energy cycle from the laboratory activity by drawing it again on a piece of paper. The data were triangulated with participants' conversation during the laboratory activity and reflective report at the end of the laboratory lesson. The interviews were given in English, as the entire student of Form Six Science is taught in English. Students were, however, allowed to respond in bilingual languages, including Bahasa Melayu and English.

In this study, the triangulation involved various methods and sources of data to create a deep understanding of a phenomenon from different individuals and different types of data (Creswell, 2012). The process used multiple data sources to compare, and cross-checking data collected from individuals with different perspectives (Merriam & Tisdell, 2016).

The interview analysis's focus was to identify cognitive relations that could be complete of sentences or part of a sentence. The interview and conversation discourse transcripts and reflective writing were coded to seek emerging cognitive relations. The analysis process

continued until the coding yielded the same results. The results applicable to the analysis were grouped in categories, and the meanings were carefully clarified with the context suggested. The objective of this study, to explore how laboratory activity with the argumentation approach, ABIIS could promote students' conceptual understanding in the Hess' law energy cycle through laboratory work, means to investigate whether the knowledge of the energy cycle took place, evaluating how the participants identify the thermochemistry reactions and form association between them.

5. Result

5.1. Interview Analysis

The researcher studied the interviews' written transcripts, and the conditions considered applicable to the problem under study were identified in the transcriptions and grouped into categories. The categories were also determined based on the explanations the participants gave for the energy cycle on a piece of paper. From these explanations, it was possible to determine how the participants formed associations for the energy cycle's thermochemistry reactions. Table 2 displays these categories and their content.

Table 2: Categories resulting from the interviews

Category	Category Contents
Suitable Complete	Start with writing balanced equations of the two reactions. Write the conversion equation of NaHCO_3 to Na_2CO_3 using Hess's Law. Produce an overall equation/ conversion equation. For the cycle, starting with the third /overall/conversion equation. It is a positive enthalpy/endothermic reaction. The arrow from NaHCO_3 is upward because of positive enthalpy. The arrow from NaHCO_3 is upward because of an endothermic reaction. The arrow from NaCl to Na_2CO_3 is upward because of positive enthalpy. The arrow from NaCl to Na_2CO_3 is upward because of an endothermic reaction.
Suitable Vague	Start with writing balanced equations of the two reactions. Write the conversion equation of NaHCO_3 to Na_2CO_3 using Hess's Law. Produce an overall equation/ conversion equation. For the cycle, starting with the third /overall/conversion equation. Not referring to positive enthalpy/endothermic reaction when the arrow from NaHCO_3 is upward. Not referring to positive enthalpy/endothermic reaction when the arrow from Na_2CO_3 is upward. Not referring to positive enthalpy/endothermic reaction when the arrow from NaCl to Na_2CO_3 is upward.

The analysis result showed that most of the participants could write the correct thermochemical equations from the experiment. It was seen that the participants were able to explain the

conversion equation of NaHCO_3 to Na_2CO_3 using Hess's Law in their interviews. One of the participants gave the following explanations about the idea of the conversion equation in the interview:

S2: "... what I need to find before I start to write the energy level diagram is the enthalpy change for the third equation which is the conversion equation.....so how I got the...how I obtain the enthalpy change is I need to modify the equations...the two equations...so that I can get the enthalpy change...it...is firstly I need to look at the third equation...the conversion equation....so for the first equation...I need to...reverse it so it will become $\text{CO}_2 + 2\text{NaCl} + \text{H}_2\text{O}$ produce HCl and Na_2CO_3 ... This will make the enthalpy becomes positive, endothermic. And then overall, I cancel out the related compounds and gather them until it becomes like this..." (Suitable Complete)

A couple of participants created the correct energy cycle for the reactions, but they could not mention the reason for placing the related equations in the cycle. The category given is 'Suitable Vague'. S4 and S9 interview notes were as follows:

S4: "...I only understand the upward arrows as positive value, but I could not relate it with exothermic or endothermic... it's a bit confusing...I mean the absorbing heat or releasing heat...."

S9: "...the product is upward and above the reactant because it shows emm...all the reactions had happened..."

Hence according to the transcripts and observation on the participant during the interview, it clearly showed all the participants gave legitimate facts on the conversion equation using Hess's Law. The chemical equations were explained well through their writings. The participants showed the correct formula of the heat change, accurate calculations, and valid thermochemical equations. The energy cycle was correctly drawn with a proper flow and orientation of the arrows.

5.2. Group Conversation Analysis

The interview analysis is triangulated with group conversation analysis. A transcript of a pair of participants, S5 and S1, showed that they were struggling to understand the equations related to the drawing of Hess's law cycle energy. S5 misunderstood the energy cycle drawing as Born Haber's energy cycle. It shows that, even though the concept was taught earlier to the students in the classroom, they still have a misconception about the idea. However, they had to fulfill the laboratory instruction by discussing their ideas and doubts about the group's concept. This part of the discussion is called Develop Preliminary Argument in the ABIIS instruction. The transcripts were as follows:

S6: KA3 is endo, but why the value is negative?

S5: Because first, we let it reverse.

S6: We calculated this, and we need to write that

S5: How to balance this equation? If we add acid, what will it produce

S6: Water.so. This one will be sodium chloride.

- S5: Then, NaHCO_3 adds with HCl . Are we looking for lattice energy?
S6: This is not about lattice energy.
S5: So... we are doing Hess's law, using Hess's law. But which one?

The pair was almost given up on their task to draw the cycle. But they kept on giving ideas to each other. However, S5 was very patient to S6 and let her guide the argument until they came up to an appropriate solution. The transcripts were as follows:

- S6: Because we need to cancel that NaCl . So, we need to multiply by two. So, this one will be extra. Hmm..there should be an explanation for this. Do you get the idea? See, no clue at all.
S5: So, this will just disappear?
S6: No. I think this one should add hydrogen gas.
S5: But the other one has no hydrogen gas.
S6: Then, if not, we just add H_2O water. Formation of water. Because this thing can be cancelled out. Yes. That's why I'm very sure we need to add another equation here.
S6: Going up, right, Lily?
S5: Yes. Endothermic.
S6: This is the route, right? This one goes up, and I think the other one goes down.
S5: Below, becomes NaCO_3 .
S6: Are we going to use the altered equation here?
S5: Ooo, yes. We do...
S6: But wait, where does this one go? Is it supposed to go up or go down? Then which one?
S5: Going up. Because this one is endothermic, it goes down.
S6: It should be indifferent routes. Wait, these are all positive?
S6: This NaHCO_3 , 2 NaCl plus CO_2 .
S5: Let see, does it balance?
S6: Okay. This cycle is correct. The arrows go with the flow, then slash.

After making lots of effort in drawing the energy cycle, fortunately, the pair managed to overcome their confusion and come up with an answer. They managed to recall back their memory on the concept and agree with their energy cycle drawing.

5.3. Reflection Report

S5 and S6 expanded their teamwork and shared their ideas with all the participants in the entire class. Both of them agreed with the notion that their understanding of the Hess's Law concept was better through the laboratory activity. The transcripts of their reflection report were as follows:

S5 wrote:

We thought that we had limited ideas at first because it was only between us two as a group, but when the argument session started, we had our rounds of discussion with all the entire groups. From there, I can share my ideas and knew my mistakes. I always thought that experiments are complicated. But now, I'm starting to make sense of all of it.

S6 wrote:

It was easier to catch up when doing the investigation. The questions given were like educating us. It helped us to improve our understanding of the lab.

6. Discussion

The findings of this study show participants' development in the conceptual understanding of Hess's Law energy cycle due to verbal argumentation. According to Hess's Law concept, all participants managed to write and correctly explain the related conversion equation. Only 13% of the participants could not relate the ideas of exothermic and endothermic processes in the energy cycle. It was found that the participants did not perform the tasks as in Table 1, in pairs as directed by the teacher. They split up the tasks that were supposed to be done in pairs to speed up their work. They viewed it as the only correct way of performing laboratory tasks. The participants had missed out on the argumentative discourse they were supposed to do to engage in learning. Group argumentation is considered a critical factor in student progress (Heng, Surif, & Seng, 2014). When small-group members are introduced to scientific activities, it creates opportunities for them to participate in debatable arguments that the other groups will accept or oppose (Jaraie & Lajium, 2019).

The interviews in this study helped describe how the participants associated the concepts of Hess's Law in the energy cycle and which learning problems they encountered. The data revealed that the participants successfully explained the equations in which they were asked to form conversion, considering the experiment's reagents. This study has also shown that 16% of the participants that did not follow the requirement to work in pairs have confusion in their ideas of exothermic and endothermic processes. This confusion is predictable as learners generally have considerable difficulty differentiating between heat energy and temperature (Niaz, 2006).

Participants have a clear understanding of the Hess's Law concept as they can apply the ideas gained through group argumentation in the laboratory. Their prior knowledge also significantly impacts conceptual understanding development, as there is a relationship between argumentation discourse and conceptual knowledge in solving problems (Asterhan & Schwarz, 2007; Asterhan, 2018). Open questions by teachers to participants throughout the laboratory activities are essential to support understanding because teachers are not looking for specific answers when questioning them (Mcneill & Pimentel, 2009), but encourage them to develop their thinking and consider the claims and opinions of other fellow participants.

7. Conclusion

This study shows the argumentative discourse has a significant influence on conceptual understanding in the Hess's Law energy cycle. Discussions, where students can make constructive comments, ask questions, discuss their ideas and provide immediate feedback, are considered one of the most powerful methods for constructing information (Cross, Taasoobshirazi, Hendricks, & Hickey, 2008). Generally, argumentation on scientific issues does not occur naturally in the school laboratory. Students have to be instructed and encouraged to engage in argumentation on a scientific concept. Therefore, it is suggested to emphasize argument-based inquiry (ABIIS) in laboratory work to develop their conceptual understanding of chemistry concepts.

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