The Evaluation of Students' Written Reflection on the Learning of General Chemistry Lab Experiment

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ABSTRACT

Reflective writing is often used to increase understanding and analytical ability. The lack of empirical evidence on the effect of reflective writing interventions on the learning of general chemistry lab experiment supports the examination of this concept. The central goal of this exploratory study was to evaluate the students' written reflections about experimental work. This study used an instrument, pre- and post-intervention design. Data were collected in the form of individual reflective writing reports by students enrolled in the first semester of a general chemistry course. Our findings indicated that the treatment group had a statistically significant increase ($p = .000$) on the posttest test after a week of reflective writing was administered when compared to the control group. Students' reflective writings were evaluated in the aspects of knowledge, critical thinking and applications. In the case of knowledge, our findings were particularly interesting as higher level of students' knowledge understanding was associated with the experimentation. The results of this study make it imperative for School of Pharmacy (SoP) and Health Sciences (SoHS) at this institution to consider including reflective writing in lab experiments.

Keywords: *Reflective writing, general chemistry, pre- and post-intervention, lab experiment, first semester*

INTRODUCTION

Chemistry is the science of matter concerned with the composition of substances, structure, properties and interactions between them. Chemistry is often regarded as a difficult course, an observation that sometimes repels learners from continuing with studies in chemistry. Chemistry is one of the most important branches of science; it enables learners to understand what happens around them. Because chemistry topics are generally related to or based on the structure of matter, chemistry proves a difficult subject for many students (Taber, 2002). General chemistry is a study of science that provides understanding of the properties of all materials and the changes they undergo; this understanding has many practical applications including drug discovery and development. Laboratory work is a core component of chemistry courses across the world. Unfortunately, research in science education indicates that conventional laboratory activities often fail to engage students in discussion and analysis of central concepts and ideas, and does not effectively promote development of inquiry skills (Hofstein & Lunetta, 1982, 2004; Singer, Hilton, & Schweingruber, 2006).

Laboratory experimental work traditionally involves students working in small groups (Singer et al., 2006). Analysis of interactions during traditional laboratory work suggests that lab talk is very goal-oriented. On-task conversations and actions are largely focused on managing and completing lab work and tend to be characterized by brief, fragmented utterances (Carlsen, 1991; Tapper, 1999). Student talk during experimental activities is mostly centered on procedural issues related to carrying out specific experimental tasks or how to manage lab equipment (Russell & Weaver, 2011; Sandi-Urena, Cooper, Gatlin, &

Bhattacharyya, 2011). In general, the nature of group member interaction has been shown to strongly influence the quality of collaborative group work (Volet, Summers, & Thurman, 2009). Students can reflect on the processes and products of group work. When incorporating reflective activities into group work, it is important that students have the opportunity to apply what they have learnt through their reflections to future tasks to improve their learning.

Reflective writing is a pedagogical strategy that can increase critical thinking in students (Craft, 2005; Heinrich, 1992; McGuire, Lay, & Peters, 2009; Rooda & Nardi, 1999). Reflection enables learners to develop critical thinking skills essential to decision-making and practice (Brookfield, 1987; Branch & Paranjape, 2002; Westberg & Jason, 2001). Reflection encourages learners to take control of their own learning needs, facilitating their professional development, problem solving, and lifelong learning. It is a process allowing individuals to revisit and analyze their experiences for better understanding and ultimately for improving practice (Schön, 1987; Brookfield, 1987; Branch & Paranjape, 2002; Johns, 2004; Plack & Greenberg, 2005). Effective writing requires critical thinking and the analysis of experiences to construct deeper meaning from those experiences. It can prompt discussion about such things as personal biases and their impact on the decision making process (Plack et al., 2007). Critical thinking is generally thought of as a process of analyzing, synthesizing, and/or evaluating information (Paul & Scriven, 1987). For decades, the concept of critical thinking has been recognized as an essential outcome for students at all levels and in all disciplines (Reed & Kromrey, 2001).

Our central goal was guided by the following research question: Does reflective writing affect students' reflection to develop better knowledge, critical thinking and application skills in experimental chemistry tasks?

METHODOLOGY

Overview of Design Study

The student body is composed of 382 undergraduate students representing the entire population of Semester 1 Pharmacy and Health Sciences programs in the International Medical University, Malaysia. The School of Pharmacy (SoP) and Health Sciences (SoHS) at this institution offers a one-semester general chemistry module for pharmacy and health sciences programs. Students in this module attend a 180-min weekly laboratory where they work in groups of 2 people supervised by a lecturer and demonstrator. On average, 32 students are divided into 16 groups in each laboratory for experimental work. Most experiments in the general chemistry module involve students in applying titration and weighing techniques.

Evaluation Measures

This study represents part of a research project on Semester 1 students' inclination to reflect when engaged in general chemistry experimental work. The intervention used was reflective writing and the instrument used was a pre- and post-intervention test. The intervention part seeks to reflect students' thinking while attempting chemistry experimental work and the instrument part is aimed at characterizing their learning thinking in the pre- and post-intervention test design for one experiment. This study shares how students' reflective responses to these tasks are encouraged and analyzed. It may hopefully help students become more reflective in their learning habits. The intervention of the study was adapted and modified from Xu and Talanquer (2012). The instrument involved was developed by researchers and has been used among undergraduate students. Two panels of experts from a local university have validated the instrument contents.

The results of this study are based on data collected in experimental work taught by the same lecturer and demonstrator during the first semester of general chemistry. The demonstrator was a Ph.D student in chemistry with experience teaching general chemistry labs. Reflective writing began after about 3 hours (one session) of experimental work in the general chemistry module. This reflective writing is at an appropriate level, with most of the required theory having been covered in lectures. The written output may indicate how much the students understood the experimental work. In particular, we obtained copies of individual reports written by one member of each student group in every lab experiment involved.

Ethical Considerations

All participations were informed of the study by the researcher. Participation was voluntary, with no consequences to students who declined participation or to participants who withdrew from the study. Participants were randomized into the control and treatment groups. Scores were saved into a password-protected computer database.

Data Collection

During the first week of experimental work, the Principal Investigator (PI) visited the students and explained the study and writing components. All participants were informed of the dates, times, and locations for the pre- and post-intervention tests. The pre-intervention test was administered to participants at the beginning of the semester. The pretest-posttest specifically designed for students consisted of five short answer questions, respectively. Pretest was carried out to identify what students already know while the posttest ascertained what students have learned from their experimental work after a week of reflective writing treatment was given.

The main results of our study are based on data collected in laboratory classes. Individual reflective writing by students was collected. More detailed information about the composition of these student groups and the experiment they did is presented in Table 1. Given that students in the G3 and G4 labs (control group) were not asked to complete reflective writing for the experiment, the number of collected reflective writing reports was 191.

Table 1: Characteristics of the groups and experiment

Experiment	Student Group	Number of Students	Lab Experiment	Number of Reflective Writings Collected
1	G1	96	Determination of chloride concentration by Volhard's method/titration	191
	G2	95		
	G3	96		
	G4	95		

Students' writing prompts in this reflective writing section were adapted from Xu and Talanquer (2012):

1. What did you learn in this lab?
2. What do you not completely understand?
3. What are the challenges you have in this practical?
4. How would you improve what you did?
5. How have your ideas changed as a result of this lab?
6. What is/are the safety consideration/ precautions for this practical?
7. How do you apply the concepts learned in this practical?

Our rubric in reflective writing, which is included in this paper focused on the analysis of seven key activities which are factual knowledge, conceptual knowledge, procedural knowledge, metacognitive knowledge, problem solving, critical thinking and applications (Xu & Talanquer, 2012). This rubric was applied to evaluate the level of *knowledge* (factual, conceptual, procedural and metacognitive knowledge), *critical thinking* (problem solving) and *applications* that students have achieved in their experimental work.

The week after reflective writing, a posttest consisting of five short answer questions was administered to the students in the same quiet, comfortable classroom setting where they took the pretest. Our posttest rubric focused on the analysis of three key activities; obtaining experimental work background information, interpreting data to generate explanations and reflecting on the experience.

Data Analysis

The statistical analysis was performed using SPSS 20.0. A non-parametric Wilcoxon signed-rank test was performed and any *p*-values smaller than .05 were considered significant. A process of analysis of the written reflections led to identification of three major types of reflective statements (general codes), each of them divided into different subtypes (specific codes). Table 2 includes the list of general and specific codes in our analytical system, together with concrete examples from the data. Codes were assigned to capture different types of reflective statements made by the students regarding *knowledge*, *critical thinking* and *applications*.

Table 2: Coding categories for students' written reflections with some example text extracts

General Codes	Specific Codes	Example Quotes from Students' Reflective Writing
Knowledge	Factual Knowledge	I learned what the actual meaning of "Volhard's titration" method is. I had heard the term before, but I now know the exact meaning of that.
	Conceptual Knowledge	This lab directly tied into what we have been learning in lecture about titration using Volhard's method. In order to determine the concentration of chloride ions in a sample solution, we can use this experimental method.
	Procedural Knowledge	I learned the correct titration and weighing method. I also learned only two-three drops of indicator are used for each titration.
	Metacognitive Knowledge	A question did arise during experimentation, which I still do not fully understand. I also aware of safety demand of surroundings; wear safety glasses, labcoat and gloves all the times [sic] in the laboratory.
Critical Thinking	Problem Solving	The challenge that I have is over-titrated [sic] during the titration process. I have to observe closely to the color change when I repeated the titration.
Application	Application	This method would be very helpful in determining the concentration of any ions in a sample solution.

RESULTS AND DISCUSSION

The sample of 382 students (n = 191 from School of Pharmacy (SoP) and n = 191 from School of Health Sciences (SoHS) programs) meant that 191 participants were in the control and treatment groups, respectively. Of the control and treatment groups, respectively, 96 (50.3%) were from SoP and 95 (49.7%) were from SoHS. According to the non-parametric test, Wilcoxon signed-rank test, there was no statistically significant difference between control and treatment groups in the pre-intervention test for E1 (p = 0.631; z = -0.480).

In the post-intervention test, there was a statistically significant difference between control and treatment groups (p = 0.000; z = -11.390). Pre-intervention test, which was administered a week before experimental work, was accompanied by theory having been covered in lectures without requiring students to do reflective writing. The students were then given reflective writing treatment after experimental work along with an administration of post-intervention test. To see the students' possible improvement, results from the two tests were compared. Description of the data gained by Wilcoxon signed-rank test is presented in Table 3 and Table 4.

Table 3: Wilcoxon signed-rank test statistics of pre- and post-intervention shown by groups

	Pre-intervention test		**Post-intervention test**	
	Control group	Treatment group	Control group	Treatment group
Z	-0.480		-11.390	
p	0.631		0.000	

Table 4: Wilcoxon signed-rank descriptive statistics of pre- and post-intervention shown by groups

	Pre-intervention test		**Post-intervention test**	
	Control group	Treatment group	Control group	Treatment group
N	191	191	191	191
Mean	2.199	2.157	2.262	4.288
SD	0.866	0.949	0.824	0.825

As shown in the tables, the pre-intervention test did not show statistically significant difference between the control and treatment groups. The most noteworthy result was the statistically significant increase in the post-intervention test when compared to the pre-intervention test. This increase may be explained by accepting that the intervention of reflective writing treatment helped make students more "eager to seek the best knowledge, more courageous about asking questions and more honest pursuing inquiry" (Facione, Facione, & Sanchez, 1994). As suggested in the literature, the reflective writing treatment may have helped students to question the truth, validity and accuracy of the information they were receiving; and it could have given them the courage to ask questions (McGuire et al., 2009).

This idea is supported by McGuire et al. (2009) who found that reflective writing as a pedagogical strategy allows students to integrate their thoughts and experiences with didactic material in order to more adequately understand both the experiences and the didactic material, and with this understanding comes courage to question circumstances in the experimental work setting. Luthy, Peterson, Lassetter, and Callister (2009) stated that writing tasks promote effective learning and writing. The study results indicated that the reflective writing treatment might have helped encourage student learning, which in turn prepares them to communicate more professionally and courageously with other health care professionals in future.

Focus on Reflective Writing

Analysis of students' reflective writing drew out three major types of reflective statements categorized as *knowledge*, *critical thinking* and *application.* The presence of these types of statements was likely influenced by the questions used in the reflective writing treatment to guide students' reflections. Overall, students invested the largest portion of their reflections (44.9%, *SE* = 1.7) in writing about knowledge acquired as a result of experimental work (*knowledge*). Second, students think critically about laboratory methods, results and problems solving (*critical thinking*: 22.4%, *SE* = 1.3) and lastly students reflected upon potential applications of their experimental work (*applications*: 32.7%, *SE* = 1.5). As shown in Figure 1, the relative weight of reflection changed with the different types of reflective statements.

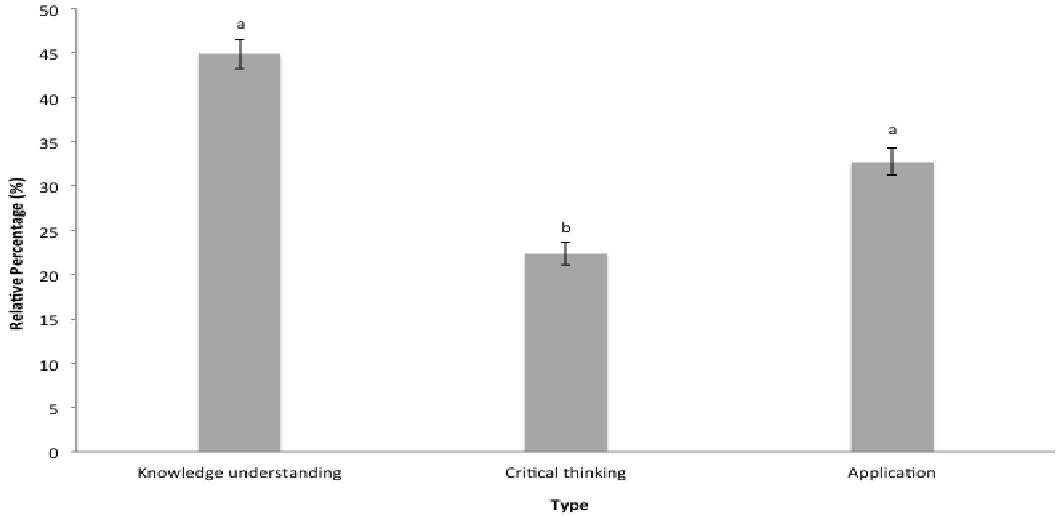

***Figure 1*. Relative weight of the types of reflective statements in students' written reflections of experimental work. Different letters indicate significant difference at the level of *p* < .05**

Students' reflective statements about different types of knowledge gained as a result of experimental work elicited four major types. These included factual, conceptual, procedural and metacognitive knowledge. As part of their reflections, students also think critically about their experimental work and this elicited problem solving skills. Students also reflected on potential application of their results to solve or understand other problems from their experimental work. Working in the lab seemed to promote more reflections not only about knowledge of experimental skills or procedures, but also about what was understood or not as a result of lab work.

Our study was designed to explore the effect of reflective writing on students' reflection to develop better knowledge, critical thinking and application skills in experimental chemistry tasks According to the data from this study, changes in the level of types of reflective statements of experimental work seemed to correlate with statistically significant changes in the pre- and post-intervention test. These changes were noticeable in the areas of knowledge, critical thinking and applications. In the case of knowledge, the results were particularly interesting as higher level of students' knowledge understanding was associated with the experimentation. In particular, students were more motivated to make knowledge understanding reflections about the extent to which they understood relevant concepts, ideas or methodologies. Engagement in guided-inquiry experiment seemed to make students more inclined to reflect on the relevance or value of their experimental results for solving problems.

The results of our study are in line with those of related investigations that highlight the benefits of engaging general chemistry students in more open investigations (Hand & Choi, 2010; Russell & Weaver, 2011). However, our findings also underscore the need for explicit interventions to improve the quality of students' reflections, particularly in critical thinking. From our perspective, reflective thinking requires that we help demonstrators to become better at motivating, pressing, and guiding students to talk about chemistry concepts and ideas in the laboratory.

CONCLUSION

This study tested the effectiveness of a reflective writing intervention, based on the Xu and Talanquer (2012) model in Pharmacy and Health Sciences degree program students. We found a statistically significant difference between control and treatment group from pre- to post-intervention tests; much valuable information was gleaned from this study. An innovative intervention that used a convenient format of administration, completion, and submission was implemented. The researchers' extended understanding of this intervention, based on the statistical data, is that this reflective writing intervention did contribute to an increase in truth seeking in participants. Therefore, this intervention may help the students seek the best knowledge in experimental work effectively. The interventions received some positive feedback. Following the intervention, several participants stated that the amount of writing and time involved was reasonable, the questions were clear, and they were encouraged to reflect on important aspects of experimental work.

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