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Investigating the Influence of the Level of Inquiry on Student Engagement

Emily K. Faulconer[1]

Abstract

Previous studies investigating student-generated questions in a laboratory class compared inquiry to a traditional approach without characterizing the inquiry level. This study investigated the influence of inquiry level on the quantity and quality of student-generated questions over one semester in a General Chemistry course with 356 participants. The researchers studied two types of inquiry in labs: structured inquiry and open inquiry. Quantity and quality of student-generated questions were analyzed and student attitudes were measured using a LIKERT survey while content knowledge was assessed via post-test. A close relationship was not found between the level of inquiry and the quantity or quality of student-generated questions, student attitudes or content knowledge. However, the data highlighted the importance of the teacher in the quantity and quality of student questions.

Key Words: inquiry, student-generated questions, engagement, cognitive level

1. Introduction

Inquiry in the classroom is well regarded in academia as a best practice that is critical to scientific literacy (Minstrell & van Zee, 2000; National Research Council, 1996). While researchers do not agree on the same operational definition of inquiry in the laboratory, several consistent characteristics appear. In inquiry, laboratory activity structure mirrors authentic science, where students take an active role in developing and asking questions as well as executing techniques.

Gradations of inquiry exist on a scale; with previously-developed frameworks to characterize undergraduate inquiry (Brunner, 2012; Buck, Bretz, & Towns, 2008; Bybee et al., 2006; Fay, Grove, Towns, & Bretz, 2007; Fuhrman, 1978; Lederman, 2004; Smith, 1971). Inquiry labs do not use step-by-step instructions, which are sometimes teacher-provided and in other cases is student-devised with guidance from the instructor (Table 1). Students design their own methods of communicating results and drawing conclusions in all levels of inquiry.

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Table 1: Rubric for characterizing the level of inquiry in a laboratory setting
(Modified from (Buck et al., 2008; Fay et al., 2007)

Characteristic	Level 0: Confirmation	Level ½: Structured Inquiry	Level 1: Guided Inquiry	Level 2: Open Inquiry	Level 2.5: Exploration Inquiry	Level 3: Authentic Inquiry
Problem/Question	T	T	T	T	T	S
Theory/Background	T	T	T	T	S	S
Procedures/Design	T	T	T	S	S	S
Results/Analysis	T	T	S	S	S	S
Results Communication	T	S	S	S	S	S
Conclusions	T	S	S	S	S	S

Where T = teacher-provided and S = student-generated

One way that the National Science Education Standards (NSES) describes inquiry is in terms of cognitive abilities; identifying and posing scientifically oriented questions has been categorized as a cognitive ability (Bybee, 2000). Several models for inquiry place student questioning as the first step and questioning is widely recognized as an important component in real world problem-solving and decision-making processes (Dori & Herscovitz, 1999; Shepardson & Pizzini, 1991; Zoller, 1987; Zoller, Tsaparlis, Fatsow, & Lubezky, 1997). Several studies have shown that providing students opportunities to pose questions has potential to increase both critical thinking and creative thinking skills (Cuccio-Schirripa & Steiner, 2000; Pedrosa-de-Jesus, Moreira, Lopes, & Watts, 2014; Shodell, 1995). The instructional strategies and lesson structures implemented by the instructor are known to influence student questioning (Albergaria Almeida, 2010; Albergaria Almeida, 2012; Pizzini & Shepardson, 1991) .

Despite the educational benefits of student-generated questions, teachers are often the ones posing content questions to the students (e.g. “Why a 10 mL won’t graduated cylinder work for this measurement?”) or the teachers must prod students to ask questions. The rare student-generated question tends to be a lower-level, informative question (Dillon, 1988). Several researchers have proposed methods of analyzing the cognitive level of a question primarily by either defining the type of answer the question requires or categorizing the vocabulary used in the question (Coutinho & Almeida, 2014; Cuccio-Schirripa & Steiner, 2000; Dori & Herscovitz, 1999; Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005; Pizzini & Shepardson, 1991; Yamamoto, 1962; Yarden, Brill, & Falk, 2001). Hofstein (2005) provides examples of lower-order and higher-order questions, with lower-order questions requiring a single word or statement answer and higher-order questions requiring further investigation. However, the author does not provide a framework for classifying student questions. Yamamoto (1962) classified questions based on the interrogative pronouns, adverbs, or verbs used. Albergaria Almeida (2014) presented a categorization scheme that identifies functions, characteristics, and typical expressions for the cognitive levels of closed (low level) and opens (high level). Pedrosa-de-Jesus et al (2014) sorted critical questioning into three domains: knowledge, skills, and attitudes/dispositions.

Previous studies have found that inquiry labs improved chemistry students’ abilities to ask high level questions (Hofstein, Shore, & Kipnis, 2004; Hofstein et al., 2005). However, both studies used traditional approaches as the control and neither described the actual level of inquiry applied. This study sought to investigate the influence of the level of inquiry on student engagement, measured by the quantity and quality of student questions and LIKERT survey responses regarding attitudes towards chemistry and the classroom experience.

2. Methods

2.1 Research Setting& Population

For the 100-level General Chemistry undergraduate college course, two laboratory exercises were developed, each with two approaches: structured and open inquiry (N = 356). For the two-semester research period, the undergraduate student population consisted of two groups, the higher level of inquiry (open inquiry, n = 214) and lower level of inquiry (structured inquiry, n = 142).Each instructor implemented the structured inquiry lab in one section and the open inquiry in a separate section (Table 2).

The labs addressed gas laws and acid-base titration, though stoichiometry and limiting reagent concepts were also a necessary component of each. The typical student arrangement in the chemistry laboratory was small groups of two or three students.

The structure of inquiry lab sessions is presented in Table 3. The modifications between the structured inquiry and open inquiry occurred during the "Engage" phase. The lab manual provided the Question of the Day, content background, and an overview of specific laboratory techniques to student in both open and structured inquiry. Step-by-step procedures were not provided to either group but the experimental procedures were explicitly outlined by the instructor during the "Engage" phase in the structured inquiry groups while students in the open inquiry groups devised their own procedures. Within the structured inquiry groups, instructors also discussed the possible results of the experiment and how to best analyze the data obtained.

2.2 Research Tools

Each laboratory section was video recorded and analyzed for student questioning during the initial instructor-student interaction prior to physical engagement with the laboratory exercise. The LIKERT survey regarding student attitudes was administered electronically as a component of the post-lab exercise.

Table 2: Organization of study

	Gas Laws		**Acid-Base Titration**	
	Structured Inquiry	**Open Inquiry**	**Structured Inquiry**	**Open Inquiry**
Instructor A	Section 1	Section 5	Section 1	Section 5
Instructor B	Section 2	Section 3	Section 2	Section 3
Instructor C	Section 4	Section 6	Section 4	Section 6

Table 3: Outline of inquiry laboratory sessions by 5E Phase (Bybee et al., 2006)

5E Phase	**Phase in Experiment**	**Cognitive Abilities** (Olson & Loucks-Horsley, 2000)
Engage	Review the Question of the Day (QOD) Ask & Answer Foundation Questions	Identify questions
	Formulate a Hypothesis and plan experiment to answer QOD	Design scientific investigation
Explore	Gather equipment and supplies to conduct the experiment Conduct the experiment and make observations	Conduct scientific investigation
Explain	Analyze data in small groups	Formulate and revise scientific explanations; Recognize and analyze alternative explanations
Elaborate	Determine method of communicating results and disseminate	Communicate a scientific argument
Evaluate	Reflection activity (Post Lab)	Reflect upon development and evolution of knowledge claims

2.3 Data Analysis: Quantity of Student Questioning

One goal of this study was to investigate the possible correlation between the level of inquiry and the quantity of student-generated questions, assessed by quantifying the participation rate in a given laboratory session. The participation rate was established as the ratio of students that posed questions to the class size. These parameters were analyzed quantitatively using statistical analyses. To determine if variances of the two populations was equal or unequal, an F-test was performed where if F>F Critical one-tail, the null hypothesis was rejected and the variance of the populations was unequal. To test the null hypothesis that the means of two populations were equal, a t-Test was performed where if t Stat < - t Critical two-tail or t Stat > t Critical two-tail the null hypothesis was rejected, indicating a statistically significant difference in the means of the two populations.

2.3 Data Analysis: Quality of Student Questioning

Using the framework in Albergaria Almeida (2014), student questions were categorized according to their cognitive level (open or closed).

Typical expressions such as "what", "where", "how", and "if … then" were used to identify the function (e.g. information, understanding, evaluation). However, these parameters served as a guide only. For example, it was possible for a student question that started with "why" to fall into either a closed or open cognitive level, depending upon the intent of the question. The variance and significance of the difference of the means were determined using F-tests and t-Tests.

2.5 Survey

The survey to measure student attitudes towards chemistry and their learning experience was modified from the Chemistry Attitudes and Experiences Questionnaire and Science Laboratory Environment Inventory (Coll, Dalgety, & Salter, 2002; Fraser, Giddings, & McRobbie, 1995). LIKERT survey responses were converted to numerical values where "strongly agree" was assigned a value of 5 while "strongly disagree" was assigned a value of 1. The variance and significance of the difference of the means were determined using F-tests and t-Tests.

3. Results and Discussion

The data shows there was not a relationship between the level of inquiry and the quantity or quality of student-generated questions (Table 4). F-Tests for the data sets indicated equal variance. The t-Tests indicated no statistically significant difference between the means for 0.5 and 2.0 level inquiry for the measured parameters. Coutinho (2014) investigated several strategies to promote student questioning in the science classroom and also was not able to establish a close relationship between the strategy and the cognitive level of the student-generated questions.

Table 4: Quantity & Cognitive Level of Student-Generated Questions at Two Levels of Inquiry

Parameter (Standard Deviation)	0.5 Level Inquiry	2.0 Level Inquiry
Mean Number of Student-Generated Questions	6.25 (±4.1)	6.98 (±3.1)
Average % Participation	29.25 (±10.1)	31.75 (±16.8)
Mean Number of Closed Questions	5.75 (±4.2)	6.00 (±3.0)
Mean Number of Open Questions	1.30 (±0.9)	1.10 (±0.4)

It is important to note that the teacher's attitudes and behaviors affect the type of questions asked by students and that instructor modeling of critical questioning has been shown effective (Rosenthal & Zimmerman, 1972). While a more detailed study into this possibility is warranted, it appears that this data set supports the premise that the instructor has a large influence on the quantity and quality of student questions (Table 5). In addition to the number of questions generated and the participation rate in the section, the cognitive level of the questions also varied by instructor, with students in a section with a more experienced instructor asking more open questions than those in sections with less experienced instructors. Despite the lack of a trend, the questions posed by students still provide valuable insight to the instructor regarding the degree of preparedness of the students to engage in the laboratory. Example student-generated questions are presented in Table 6.

Table 5: Comparison of Instructor on Quantity of Student-Generated Questions (data is composite from both semesters of the 2.0 Level Inquiry Labs)

	Average Number of Student-Generated Questions	Average Participation Rate (%)
Instructor 1– most experienced	9.5	57
Instructor 2– least experienced	3.5	19
Instructor 3	8.5	33

Table 6: Select Student-Generated Questions at Various Cognitive and Function Levels

Cognitive Level	Function	Question
Closed	Understanding	How can stoichiometry be used to decide the mass of reactants to use?
Closed	Information	What is the density of the acid solution?
Closed	Information	What is our limiting reactant?
Open	Evaluation	What happens to the copper when exposed to the hydrochloric acid?
Open	Relationship	Will temperature meaningfully affect the experimental results?
Open	Relationship	What would happen if the magnesium escaped the copper wire cage and floated to the top of the eudiometer?

The survey to assess student attitudes regarding the lab design and confidence levels showed inconsistent variations based on level of inquiry and no differences were found to be statistically significant (Table 7). The p-value for all questions was over 0.05. Both of the laboratory exercises were within the spectrum of inquiry. Students made many selections during the lab experiments including what reagents would be most appropriate, given a selection. At the 0.5 level of inquiry, the protocol was given to the students while at the 2.0 level students decided what experimental approach would be appropriate to answer the Question of the Day. Despite this difference in approach, there was little difference in the students opinions on whether the instructor had provided a protocol for carrying out the experiment, with average LIKERT responses for the 0.5 and 2.0 levels of “neutral” and “neutral/agree”, respectively. To add validity to the response to this question, the same concept was asked from a different perspective: students decide the best way to proceed during the lab experiments. This question also did not have a statistically significant difference between the levels of inquiry, with both the 0.5 and 2.0 levels responding between “neutral” and “agree”. The survey also did not reveal any changes based on the level of inquiry for student confidence in asking meaningful questions.

Table 7: Analysis of Select LIKERT Survey Questions Regarding Student Attitudes

Question	Average Response (SD) for 0.5 Level	Average Response (SD) for 2.0 Level	P value
The instructor decides the best way to carry out the laboratory experiments	3.01 (1.07)	3.47 (1.21)	0.143
Students decide the best way to proceed during the lab experiments	3.34 (0.92)	3.81 (0.98)	0.071
I am confident in my ability to pose meaningful questions that could be answered experimentally	2.92 (0.60)	2.82 (0.79)	0.689
I am confident in my ability to ask foundation questions to establish background knowledge, resources, and appropriate methodology toperform an experiment	2.94 (0.63)	3.01 (0.91)	0.705

Alpha = 0.05

Where a response of 1 indicates strongly disagree and a response of 5 indicates strongly agree

Although the research question focused on the influence of inquiry on student questioning and attitudes, the Post-Lab exercise also included several multiple-choice content questions of varying difficulty. Analysis determined that there was no statistically significant difference between instructors, between the mean performance for each of the two lab activities, and the mean performance between the two levels of inquiry (Table 8).

Table 8: Sample Statistical Analysis of Content Knowledge Quiz Results

Data Set A	Data Set B	Mean Performance (SD)	Mean Performance (SD)	P value
Instructor 3 Lab 1 Level 0.5	Instructor 2 Lab 2 Level 0.5	68.2 (20.4)	69.2 (24.6)	0.864
Instructor 3 Lab 1 Level 0.5	Instructor 3 Lab 2 Level 0.5	70.8 (25.2)	68.6 (15.9)	0.679
All Sections Level 0.5	All Sections Level 2.0	70.6 (16.4)	72.1 (16.6)	0.198

Alpha = 0.05

4. Conclusions

Well-designed and implemented inquiry laboratory experiments provide the environment for students to develop important learning skills, including how to ask scientific questions. This short term study implementing a small pedagogical change did not clearly establish a trend between the level of inquiry and the quantity and quality of student-generated questions. However, this study did establish that the instructor plays an important role in student question-asking. It also revealed that increasing the level of inquiry does not damage student engagement (measured by quantity and quality of questions), student attitudes, or mastery of content knowledge. This indicates that the level of inquiry alone does not spur student engagement. It is possible that a semester-long study that provided students an opportunity to practice their question-asking may show a stronger development in their skills.

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