

DOES SCAFFOLDING HELP TO IMPROVE THE OPEN INQUIRY EXPERIENCE  
FOR CHEMISTRY STUDENTS?

by

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## ABSTRACT

New curricula seem to be placing a greater emphasis on inquiry laboratory work in the high school sciences. This study looked at how scaffolding guided inquiry chemistry experiments affected the students' ability to conduct an open inquiry experiment. The two guided inquiry labs used for the scaffolding focused on developing different design and analysis skills. Analysis of laboratory reports, observations, surveys and interviews were performed. The results showed a general improvement in terms of confidence, analysis ability, and ability to design an inquiry lab.

## INTRODUCTION

With a greater emphasis being placed on inquiry-based laboratory experiments, I am looking at how scaffolding two guided inquiry experiments will prepare my students to perform an open inquiry experiment. The school where this action research-based classroom project will be taking place is a private K-12, for profit, international school in the city of Bangkok, Thailand. The school is composed of three campuses including a Kindergarten campus, a K-2 campus and a 1-12 campus. The three campuses currently educate about 750 students with about 500 students enrolled at the grades 1-12 campus. The students come from a variety of countries from around the world with the majority of the students from Asia, predominantly from Thailand, China, and India. The school is a college preparatory school using the AP, IB® and NGSS-aligned curricula in the high school, NGSS and Common Core curricula in the middle school, and Learning by Design in the primary years.

The project will be conducted in the International Baccalaureate® (IB®) chemistry class which has 15 students in grade eleven. The class is for the higher-level students studying in the Diploma Program (DP). The project will take place in the first year of a two-year course.

Inquiry is a method that is intended to give students an experience closer to how people learn as well as being similar to an experience a research scientist might encounter. Based on my prior teaching experience and in particular a few partial inquiry-based experiments tried in my class, I have gathered that students are having trouble completing this type of experiment without significant help from the lab assistants or

from me, their teacher. In this research project I will be looking at how to further develop students' inquiry skills so that they can be successful at completing inquiry labs. Success refers to the students developing critical thinking skills in laboratory design and overall having a more positive laboratory experience. The main question for this action research-based classroom project is, "How does guided inquiry affect the students' experience in a chemistry laboratory?" The subquestions are as follows: 1) Will using two guided inquiry labs as scaffolding help to develop the students' ability to conduct an open inquiry lab? 2) Will the scaffolding develop the students' confidence in performing an open inquiry lab? 3) Will inquiry labs improve the students' attitude towards laboratory work?, and 4) Will inquiry labs improve the students' ability to analyze their lab results?

### CONCEPTUAL FRAMEWORK

Science laboratory activities traditionally have involved giving the students the purpose, procedure, data tables, and questions that lead the students to a conclusion. Although this is a valuable method for developing certain laboratory skills, this is not necessary the best method to achieve higher order learning or for teaching the scientific process. Inquiry activities have been around for over a century in schools (Barrow, 2006, p. 265-266) and recently have been receiving a renewed lease on life as teachers are looking for ways to improve the laboratory experience.

Inquiry applies to education as a means to learn and as a means to garner skills. "Inquiry is intimately connected to scientific questions - students must inquire using what they already know and the inquiry process must add to their knowledge" (National

Research Council [NRC], 2000, p. 13). Inquiry-based lessons are different from traditional lessons in that the students are challenged with questions that engage them, challenging them to search for the answers. “Every inquiry must engage students in a scientifically oriented question” (Barrow, 2006, p. 274). These questions do not come with straightforward answers that are easy to ascertain, but are designed to motivate the students to design methods to find the answers. “Inquiry proceeds by posing questions: by interrogating subject matters or reality itself so as to lay underlying connections or structures bare” (McMurtry, 1988, p. 31). Whereas traditional lessons proceeded with the teacher lecturing or providing the students with facts and information that the students were expected to remember. Inquiry turned the passive student into an active learner, developing ideas, questions, the means to find the answers and an analysis of the results. Experience isolated from understanding is not inquiry. Inquiry couples experience with understanding and one cannot be attained without the other (NRC, 2000).

Inquiry involves science practices. These practices, as explained by the National Research Council’s *A Framework for K-12 Science Education*, help students to understand scientific knowledge development, giving an appreciation of the approaches for investigating, modeling, and for explaining the world (2012). Inquiry is a modeling of scientists’ methods of developing new ideas that can turn into experiments from questions and research. The focus of practices in inquiry stems from the idea that scientists do not just follow one method, but use many methods dependent on what they are trying to accomplish (NRC, 2012). These practices, as outlined in the NGSS are: 1. Asking questions, 2. Developing and using models, 3. Planning and carrying out

investigations, 4. Analyzing and interpreting data, 5. Using mathematics and computational data, 6. Constructing explanations, 7. Engaging in argument from evidence, and 8. Obtaining, evaluating, and communicating information (NRC, 2012). A good question will lead to an answer based on scientific facts. Modeling is the process of understanding, which can be done through a variety of means from pictures, to actual scaled models, to diagram representations, maps and other abstract models. Planning and carrying out investigations involves the planning of a systematic investigation including determining what data will be collected. Analyzing and interpreting data results in the collected data gaining meaning in context of the experiment. Without meaning, collected data cannot provide much of an answer to the question that was asked. Mathematics and computation are tools that are to be used to help show relationships and patterns in the collected data. An explanation is a way of making sense of what was done during the experiment. An argument is to show the strengths and weaknesses of the explanation. Explanations need to be defended and a good way of defending an explanation is by explaining the strengths and weaknesses of it. All of this work would not do much good if it is not communicated so that other scientists can evaluate it, and learn from it. Communicating can take the form of presentations, written reports, and discussions (NRC, 2012).

“Understandings of scientific inquiry represent how and why scientific knowledge changes in response to new evidence, logical analysis, and modified explanations debated within a community of scientists” (NRC, 2000, p. 21). With this in mind, the NRC in their *Inquiry and the National Science Education Standards: A Guide for Teaching and*

*Learning*, developed 5 features that define inquiry (2000). These five features are; 1. Learners are engaged by scientifically oriented questions, 2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions, 3. Learners formulate explanations from evidence to address scientifically oriented questions, 4. Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding, and 5. Learners communicate and justify their proposed explanations (NRC, 2000). In summary, students are to act like scientists: asking questions based on science, determine what evidence needs collecting, explain their evidence, and to communicate their findings, in essence, emulating the scientific method. Inquiry is about mirroring what scientists do during the course of their work. Not all inquiry lessons need to incorporate all five of these features. The features that are incorporated into each lesson are determined by the teacher based on lesson goals and objectives. Sometimes a teacher will provide a question rather than have the students develop their own, or the teacher might inform the students what data to collect. If less than all five of the features are incorporated into the lesson, then the lesson is considered a partial, rather than full, inquiry lesson (NRC, 2000).

Inquiry has been a part of education for over a century. John Dewey recommended the inclusion of inquiry into school curriculum in 1910 (Barrow, 2006). Ever since 1937, American curriculum has been designed to include inquiry in some form (Barrow, 2006). Even with the push for inquiry in classrooms, many teachers and schools have been reluctant to implement inquiry methodology. Many reasons exist for

not including inquiry. These reasons include teachers not having enough time to implement inquiry, teachers not having the appropriate classroom management skills, limited available resources, lack of support from the school, a lack of content knowledge, an emphasis on content by curriculum and textbooks as well as due to the level of difficulty to properly implement inquiry (Barrow, 2006). Another reason comes down to traditional classroom culture where the teacher was always right and the students were not allowed to question the educational facts. Questioning was discouraged and sometimes resulted in punishment (McMurtry, 1988).

Even with so many roadblocks preventing the implementation of inquiry lessons, inquiry is still highly discussed as a means for learning not only in classroom delivery but also in laboratory experiments. Inquiry for laboratory experiments will be the focus of this action research project. Inquiry learning tends to be broken down into varying degrees of teacher control versus student control of the learning experience. There seems to be no set definition of these varying degrees of laboratory inquiry. According to Bell, Binns, and Smetana (2005), there are four main categories of laboratory experiments: verification labs (sometimes called confirmation labs); structured inquiry; guided inquiry; and open inquiry. These range from the fully teacher controlled and proceed to the fully student controlled, respectively.

Verification labs are experiments where the teacher controls the experience. These laboratory exercises are designed to verify a known idea or fact. The students are expected to proceed according to a set procedure or method to derive the same answer that someone else has already achieved, with a procedural analysis of the data provided

for the students. These activities have been used by some teachers as a way to develop novice students who are in the process of acquiring basic learning or manipulative skills while other teachers use this style after the students have learned the material or as a way to introduce new information based on previously developed ideas (Bell et al., 2005).

Structured inquiry is similar to verification inquiry except that in structured inquiry activities the students are not given the procedural analysis, challenging the students to collect relevant data and to analyze the results on their own. The students are given a question and the procedure by the teacher and are instructed to work through the steps to collect data that answers the question. These activities are typically used before the students learn the material in class. Both the verification and structured inquiry activities tend to be referred to as “cookbook” or “traditional” activities as the students follow detailed instructions from start to finish (Bell et al., 2005) but it is still possible for these cookbook labs to contain features of inquiry.

In a guided inquiry activity, a question or procedure is given to the students and nothing else. The students are expected to develop the method for finding the answer and to follow their method to gather their data, analyzing the results to form a conclusion. Guided inquiry activities can be structured inquiry activities without a teacher-provided procedure. Guided inquiry activities challenge the students to not only think about the answer and how it applies to the question they were given, but also develop the method for finding the answer (Bell et al., 2005).

Open inquiry activities involve the greatest amount of student control over the experience, requiring the most effort by the student to complete. In open inquiry

activities, the students are not given anything other than possibly a general topic for the activity and the students are expected to develop a question, to gather data, to analyze the data, and to form a conclusion. With open inquiry being student centered, it tends to take a greater amount of time. It starts with students developing their own question and designing an experiment that could lead to an answer. This gives the students ownership of the activity by giving them the means to answer their own question (NRC, 2000).

There can be a large difference between a teacher controlled experiment and a student controlled experiment. Teacher controlled experiments, verification and structured inquiry activities, tend to be designed to arrive at a preset answer to verify a known concept while guided and open inquiry activities are designed to develop the students thinking skills and conceptual understanding. This tends to be done by centering the guided inquiry activities around a real world problem while the open inquiry activities challenges the students to develop their own question or problem (Cracolice & Monteyne, 2004).

The impacts of inquiry on learning can be measured many different ways, both quantitatively and qualitatively. Regardless of the type of measurement, levels of acceptance of guided and open inquiry as well as initial and final feelings towards the amount of learning achieved during the guided and open inquiry activities were high. These impacts tend to be more positive than negative. In a study involving 240 students in two subsequent General Chemistry courses at Franklin and Marshall College, over two semesters (one full academic year) inquiry learning was compared against traditional lecture-based classes. The results from assessing the impacts of these two groups, lecture

and inquiry, inquiry showed to be more positive in learning acquisition. The impacts were seen through the use of final exams, withdrawal rates, percentages of students receiving below standard semester scores (D's and F's) and student attitude questionnaires. From increased test scores to greater confidence in learning achievement, guided and open inquiry tend to be superior to traditional lecture teaching methods. Feedback from students regarding inquiry laboratory experiments was positive (Farrell, Moog, & Spencer, 1999). This same study showed that the group inquiry work forced the students to become active learners in the classroom rather than passive members listening to a lecture. This study concluded that "Students who are active and involved in a classroom setting find it difficult not to learn something" (Farrell et al., 1999, p. 573).

In a different study involving students in a university general chemistry course for science majors, guided inquiry students tended to outperform the traditional laboratory students on experimental design and data analysis (Cacciatore & Sevian, 2009; Deters, 2005) and with the guided inquiry students outperforming the traditional laboratory students on test questions pertaining to the laboratory experiments (Cacciatore & Sevian, 2009). This study was done to record the impact of incremental changes in developing students for and in inquiry laboratory experiments. This study was to examine the difference between a complete change from traditional laboratory experiences and a slow change, developing the students to be better inquiry learners. This study involved three groups of students all receiving the same class lectures but assigned to three different laboratory groups. Two of the three groups participated in inquiry laboratory

experiments while the third group completed the traditional lab experiments that have been in use for years.

Guided and open inquiry laboratory experiments were found to increase the educational value of the laboratory experiments over traditional laboratory experiments even though an initial improvement in critical thinking skills was negated by the end of the study completed by Pavelich and Abraham (1979). By the end of the study the students performing the traditional laboratory experiments showed the same overall increase in critical thinking skills as the students completing the inquiry laboratory experiments (Pavelich & Abraham, 1979).

Another benefit of inquiry laboratory experiments found by teacher researchers is that the students who were participating in inquiry laboratory experiments asked more higher order thinking questions than students performing traditional laboratory experiments. These questions, which were measured by having teacher observers recording the number of questions asked as well as the type of questions asked, centered around the theory of the experiment whereas questions by students performing traditional laboratory experiments centered around procedure (Cacciatore & Sevian, 2009).

Implementing inquiry laboratory activities is not as easy as just removing a procedure and/or question. Students often get frustrated by the lack of procedures when first challenged with an inquiry activity (Backus, 2005). The challenges that the students face, how to approach problems and how to work collaboratively, can develop the students' ability to take responsibility and to organize their thoughts better. These

challenges can take more time but the teacher researchers found the growth in these skills were well worth the time and frustration experienced by the students (Backus, 2005; Deters, 2005).

According to a study done by Chatterjee, Williamson, McCann, and Peck (2009) based on qualitative data, the results were positive in terms of student attitudes and in student learning for both guided and open inquiry, however, guided inquiry was met more positively by students. The same study found that students tended to have a more positive attitude towards guided inquiry over open inquiry as they felt that they learned more through guided inquiry. The students felt this way since they lacked confidence in developing a procedure that solved their own problem and students were found to believe that they learned more through guided inquiry activities when surveyed. Even if open inquiry is perceived by students as a more favorable option to guided inquiry, the level of teacher control versus student control comes down to the teacher's goals for the lesson. Both guided and inquiry have their place in the science laboratory and it is up to the teacher, based on objectives and student background knowledge to determine which one or which level of student control should be used.

As inquiry activities are regarded as being a strong method for developing learning in students, it is important to develop methods to implement them into the classroom. Two different studies concluded that even though student controlled activities benefit the students learning more than controlled laboratory activities, there needs to be a plan that implements various levels of student control before an open inquiry lab should be attempted (Bell et al., 2005). This combines basic skill development and scientific

knowledge with critical thinking development. Sometimes, teacher controlled laboratory activities satisfy the goals where the students might be learning how to use a specific piece of apparatus or to introduce an idea. These traditional activities then are followed with inquiry that combines the new skills or idea with challenging the students to develop a method to solve a problem using that skill or idea.

With inquiry laboratory experiments taking more time than traditional laboratory activities and being difficult to implement in classrooms with a large number of students, methods were developed to help reduce the amount of time needed and to help accommodate large class sizes in a study by Cheung (2008). The method to alleviate the amount of time needed was to distribute the assessment criteria prior to the start of the inquiry activity to reduce the number of potential questions based on assessment. The method to accommodate large class sizes was to help alleviate the problem of many different groups working on different experiments and trying to keep it all safe and productive. This method was to have the small groups discuss possible procedures to solve a problem or to answer a question posed by the teacher then to come together in a large group setting coming to a consensus procedure that the entire class could follow.

Once it has been decided that inquiry activities are to be used in a classroom, a method of implementation needs to be chosen. Several different methods of implementation have been used in different studies. One of the most common method for implementing inquiry activities uses traditional activities to build basic laboratory skills for guided inquiry which was in turn used to build basic inquiry skills for open inquiry activities (Pavelich & Abraham, 1979; Bell et al., 2005). It is a scaffolding method

where a lab was used to develop the necessary skills students would need for the next lab. That lab is then used to develop skills needed for the lab after that until the students were properly prepared for open inquiry.

Small groups with predefined and assigned roles was also a method for implementing inquiry into laboratory and classroom activities. These groups would be challenged to perform in an inquiry activity but only within their preassigned roles. This encouraged the students to be active participants in the inquiry activity as they were each responsible for a certain aspect of the laboratory activity (Farrell et al., 1999).

While introducing the inquiry activity, the students should receive background theoretical information to help them draw conclusions from the collected data. This is in opposition to students being provided with example calculations and conclusions that regularly precede laboratory activities in traditional laboratory experiments (Cracolice & Monteyne, 2004). During the inquiry activity, the study by Cheung (2008) found that it is imperative that teachers answer questions with appropriate questions that help to guide and to check for understanding rather than just giving answers.

In summary, inquiry starts with a question, emphasizes data analysis, pattern recognition, and explanations that apply back to the original question that was asked (Mohrig, 2004). Inquiry is not new but it seems to have been lost during the development of schools over the past century. Traditional laboratory experiences have their place and are a valuable means to develop certain basic laboratory skills in novice students. Guided inquiry takes the basic skills developed by traditional laboratory activities and develops the students' ability to think critically solving a problem or question posed by the teacher

while using the skills learned in traditional activities. Open inquiry activities take it one step further in challenging the students to not need the teacher to pose the question but to question what they experience and to develop an experiment that could lead them to an answer. Inquiry activities are seen as being more reflective of the scientific process as it allows the students to investigate their learning as a scientist would (NRC, 2000).

### METHODOLOGY

The concept of inquiry has been around for over a century in schools and has been gaining in emphasis in recent years. This can be seen through the most recent International Baccalaureate (IB®) chemistry curriculum, implemented with the 2014-15 academic year and the most recent Advanced Placement (AP) chemistry curriculum, implemented with the 2013-14 academic year. Since I teach both of these curricula, I conducted my action research project on inquiry chemistry labs. The focus of this project was how the use of a scaffolding approach to student controlled (open) inquiry labs affects students' experience in a chemistry laboratory. The scaffolding approach was to use two guided inquiry laboratory experiments focusing on different parts of the open inquiry experiment. The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained.

There were four questions addressed in determining the effects of scaffolding on preparing students for an open inquiry lab. The first question was, "Will using two guided inquiry labs with different amount of student control help to develop the students in their ability to conduct a student controlled (open) inquiry lab?" The next question

was, “Will using guided inquiry labs develop the students’ confidence in their own lab skills in performing an open inquiry lab?” The third question was, “Will an open inquiry lab improve the students’ attitude towards laboratory work?” The last question was, “Will an open inquiry lab improve the students’ ability to analyze their lab results?”

### Participants

The participants in this study were students in their junior year of a private international school (K-12) in Bangkok, Thailand. All of the instruction in the school is in English except for the second language classes. The students are only accepted into the school if they have a proficiency of English that allows them to be active participants in school. This proficiency is assessed by the school’s written and oral entrance exams. There were 15 students studying in the IB® higher level chemistry class taught by me. Of these 15 students, two were considered native English speakers (being from India and Sri Lanka) with the remaining 13 students considered as second language English learners. Of the 15 students, six were female and 9 were male. Three of the students were in their first year at this school while the remaining have studied in this school for at least 2 years prior to the current academic year. The higher level IB® class that these students were undertaking was an advance level university preparatory chemistry class that consists of two years of study (junior and senior years) culminating in the completion of one internal assessment (IA) being submitted to IB® and a three paper final exam over two days covering the entire two years of study.

### Intervention

Students were assessed twice using guided inquiry lab reports consisting of varying amounts of student-generated hypothesis, variables, material list, procedure, data collection methods, data analysis and conclusion and once using an open inquiry lab report where the students developed all aspects of the process except for the experiment question. To prepare the students for this challenge the students were assessed through this action research-based classroom project in how open inquiry labs affect their laboratory experiences. Previously, the students conducted (cookbook) laboratory experiments that consisted of me giving them varying amounts of the variables, materials, procedure, data collection methods and guidance for data analysis. This project built on this method of laboratory experiments developing the experience into student-controlled experiments. The students have conducted several of these cookbook laboratory experiments prior to the start of the action research project.

The intervention occurred from January 12<sup>th</sup> until February 26<sup>th</sup>, 2015. During those seven weeks, the students were learning about chemical energetics in the classroom. The three labs that the students conducted focused on specific heat capacity of water, enthalpy of neutralization and enthalpy of dissolution.

The first lab, enthalpy of neutralization was an IB® recommended lab, designed by Vernier Software and Technology Company for IB® lab work and provided the students the opportunity to develop their own hypothesis, variable list (including the independent, dependent and the controls) and the list of materials. The students were provided with the question and the data collection methods as well as the data analysis

guide. The enthalpy of neutralization lab consisted of the students measuring the change in temperature of water when different volumes of a strong acid (hydrochloric acid) and a strong base (sodium hydroxide) were added. From this data they were to determine the enthalpy of neutralization and compare it to the literature value. For this experiment, the students submitted a lab report containing their hypothesis, variable list, material list as well as their data collection, data processing, data analysis and their conclusion.

The second lab was enthalpy of reaction as an application of Hess' Law. In this lab activity, students determined the enthalpy change when different solutions were combined. This investigation had the students developing their own procedure and data collection methods. The question, hypothesis, variables, material list and data analysis guide were provided for them.

The third lab, enthalpy of dissolution, was presented to the students as a hand warmer challenge with only a research question being provided and the students had to develop their own hypothesis, variable list, material list, procedure, data collection method, and data analysis. The research question for this lab was: "Which salt will be the most cost-effective, environmentally-friendly, and efficient in creating a hand warmer?" The first two labs should have provided students with the scaffolding necessary for them to successfully complete this third investigation.

### Comparison

The comparison was done using the laboratory reports and student attitudes concerning laboratory work from the first term of the academic year. During the first term, the students completed five physical laboratory experiments and two virtual

laboratory experiments where they were provided with the question, variables, material list, procedure (except in the two virtual laboratory activities), and data collection methods with only the data analysis and conclusion needing to be done by them (usually with guidance). The laboratory reports were collected and assessed during the first term. The topics for the comparison labs can be seen in Table 1.

Table 1  
*Comparison Laboratory Topics*

Experiment #1	Determination of the empirical formula of silver oxide
Experiment #2	Flame test activity
Experiment #3	Standardization of NaOH by two methods; phenolphthalein and drop counter with a pH meter
Experiment #4	Reaction stoichiometry
Experiment #5	Preparation and analysis of tetraaminecopper(II) sulfate monohydrate
Virtual experiment #1	Density of a liquid
Virtual experiment #2	Density of a metal

#### Data Collection

Data collection included surveys, student interviews, observations, and lab reports. These four methods of data collection were designed to show the evolution of attitude, perception of inquiry labs and capacity of lab design during the intervention. My data collection instruments are summarized in Table 2.

Table 2  
*Data Triangulation Matrix*

Focus Question	Data Source 1	Data Source 2	Data Source 3
Primary Question: How does a scaffolding approach to student controlled (open) inquiry lab affect the students' experience in a chemistry laboratory?	Pre- and post-lab student surveys and interviews	Teacher observations and surveys	Lab reports for each experiment
Sub-Questions	Lab reports for each experiment	Pre- and post-lab student surveys	Student interviews
1. Will using two guided inquiry labs as scaffolding help to develop the students in their ability to conduct an open inquiry lab?			
2. Will the scaffolding develop the students' confidence in performing an open inquiry lab?	Teacher observations	Teacher surveys	Student interviews and pre- and post-lab surveys
3. Will inquiry labs improve the students' attitude towards laboratory work?	Pre- and post-lab student surveys	Teacher post-lab surveys	Student interviews
4. Will inquiry labs improve the students' ability to analyze their lab results?	Lab reports for each experiment	Student interviews	Teacher observations

The surveys were completed by student participants and two teachers (myself and an outside teacher observer). Students completed a pre-lab and post-lab survey assessing the students' attitudes and perceptions of the lab expectations and the lab experience. These surveys were designed to show the transformation of attitude and capability during

the intervention towards inquiry labs. The teachers' surveys were designed to help them focus their observations into usable ideas for the intervention assessment. These were conducted post-observation.

I also interviewed six students from the class. These six students included two students each from high, middle, and low achievement levels. The level of achievement was determined by academic grades in the class and observed motivation. The interviews allowed these students to elaborate on their attitudes and perception of inquiry labs.

The observations by the outside teacher and me were designed to determine the attitude the students have towards inquiry lab work and the students' confidence in conducting inquiry experiments. It also allowed the teachers to note any issues or triumphs that the students experienced.

The lab report showed the students' ability to communicate their understanding. It gave them the chance to reflect while developing their ability to communicate their full understanding of the content and ability that they learned during the lab. I used the internal assessment rubrics designed by IB® (2014) to show capabilities in completing inquiry labs.

### Timeline

The time frame for this intervention was from January 12<sup>th</sup>, 2015 until February 20<sup>th</sup>, 2015. This six-week period was broken down into individual weeks with their corresponding activities.

January 12<sup>th</sup> - January 16<sup>th</sup>, week one composed of the introduction to inquiry labs, the goals and expectations. The students received the question for their third lab

which is the open inquiry lab. The six students participating in the interviews were chosen.

January 19<sup>th</sup> - January 23<sup>rd</sup>, week two included the pre- and post-lab student surveys, post-lab student interviews, teacher observations and the completion of the first lab, specific heat capacity of water lab.

January 26<sup>th</sup> - January 30<sup>th</sup>, week three had the students write their lab reports for the specific heat capacity lab.

February 2<sup>nd</sup> - February 6<sup>th</sup>, week four included the pre- and post-lab student surveys, post-lab student interviews, teacher observations and the completion of the second lab, enthalpy of neutralization lab.

February 9<sup>th</sup> - February 13<sup>th</sup>, week five had the students write their lab reports for the enthalpy of neutralization lab.

February 16<sup>th</sup> - February 20<sup>th</sup>, week six included the pre- and post-lab student surveys, post-lab student interviews, teacher observations and the completion of the third lab, the hand warmer challenge (enthalpy of dissolution).

#### DATA AND ANALYSIS

The overall feeling from the two teachers and participating students was positive in terms of student attitude and lab skills improvement. The teachers and the students felt that the inclusion of two scaffolding labs to build up to the full inquiry lab worked well and provided the students with a means for success. The data collected from the intervention showed a general positive improvement in the students' experience in the chemistry laboratory. There was a general improvement in ability, confidence, attitude

and their ability to analyze their experiments and collected data. This was not true for every student, or for every set of data collected, but looked at in its entirety, the intervention was a success, achieving the expected results.

#### Impact of Guided Inquiry on Student Ability to Conduct Open Inquiry Lab

The first two experiments were designed to develop the students' ability to conduct an open inquiry lab. The first lab, enthalpy of neutralization, was designed to allow the students the opportunity to develop the hypothesis, material list and the variable list. The second lab, Hess's Law lab, gave the students the opportunity to develop the procedure and data collection methods. The third lab, Hand Warmer Challenge, allowed for the students to design the entire lab from the given research question, "Which salt (from a given list) will be the most cost-effective, environmentally-friendly, and efficient in creating a hand warmer?". The Hand Warmer Challenge was the culmination lab where the students were able to apply the skills that they developed during the first two labs.

The results of the three intervention lab reports show that the ability of the students to write their lab reports did not improve from the first two labs to the third lab. The three lab reports were graded against the IB® IA rubric (Appendix F). The lab reports showed the students' ability to communicate their experiment, findings, analysis and conclusion. The fact that the third lab report scores were lower from the first and second shows that the students had difficulty in communicating when it came to explaining a completely self-designed and analyzed experiment. This lack of improvement was only seen when comparing the third lab against the first two as the

second lab showed an improvement for an increase in class average from 84.1% (SD = 10.6) to 89.4% (SD = 8.5) for an average improvement of 6.3% but fell for the third lab report to 82.0% (SD = 9.9) for an average decline of 8.3% (Table 5).

When the intervention lab reports are compared against the pre-intervention lab reports, it can be seen that the intervention lab reports did not improve the students' ability to communicate their lab experiments. The average for the five pre-intervention lab reports was 83.5% (Table 3) and the average for the three intervention lab reports was 85.2% (Table 4), for a 1.7% increase. I feel that this percent increase is not enough to be able to state that the intervention labs helped to improve the students' ability to communicate their experiment, it is inconclusive. While the overall scores were similar, comparing the evaluation section for the pre-intervention lab reports to the intervention lab reports, it was seen that when the students are given leading questions in the evaluation section of the report, they do much better than when they had to develop their own evaluation section. For the pre-intervention lab reports, the students averaged 94.8% for the evaluation section while for the intervention lab reports, the students averaged 78.5%.

The pre- and post-lab surveys concerned with how the students feel about these labs developing the general laboratory skills show a general improvement in skill development.

When looking at the pre-lab surveys (Table 5) for all three intervention labs, it can be seen that before the labs, that nearly all of the students felt that laboratory work in IB® Chemistry helped them to learn laboratory skills. The percentage of respondents

Table 3

*Comparison of the five pre-intervention lab reports, overall scores (N=15)*

	Experiment 1 (%)	Experiment 2 (%)	Experiment 3 (%)	Experiment 4 (%)	Experiment 5 (%)
Class average	73.60	95.30	83.06	75.19	90.50
Standard Deviation	12.00	5.18	20.34	21.57	12.52
Pre-intervention average (%)	83.53				

Table 4

*Comparison of the three intervention lab reports, overall scores (N=15)*

	Experiment 1 (%)	Experiment 2 (%)	Experiment 3 (%)
Class average	84.1	89.4	82.0
Standard deviation	10.6	8.5	9.9
Pre-intervention average (%)	85.17		

Table 5

*Student Pre-lab Survey on Student Ability (N=15) during the intervention*

I think that laboratory work in IB® Chemistry helps me to learn laboratory skills.			
	Pre-lab #1 survey /number of respondents	Pre-lab #2 survey /number of respondents	Pre-lab #3 survey /number of respondents
Strongly disagree	0 (0.0%)	0 (0.0%)	0 (0.0%)
Somewhat disagree	0 (0.0%)	0 (0.0%)	0 (0.0%)
Neutral	1 (6.7%)	0 (0.0%)	0 (0.0%)
Somewhat agree	5 (33.3%)	9 (64.3%)	11 (73.3%)
Strongly agree	9 (60.0%)	5 (35.7%)	4 (26.7%)

responding with an agree (whether strongly or somewhat) was 93.3% while for labs two and three, it was 100% for each. This is interesting as it seems that the students were thinking of pre-intervention labs (especially prior to the first scaffolding lab) while answering this question. When looking at the three intervention laboratories, the results are a bit different.

The post-lab surveys for the three intervention labs (Table 6) shows that after the intervention labs the students did not feel as confident in learning lab skills (the survey question specifically stated ‘after today’s lab’) as compared with the pre-intervention laboratories. Only 83.4% of the students agreed (combined somewhat and strongly) after the first intervention lab that the laboratory conducted that day helped to improve their laboratory skills, while only 55.5% agreed after the second lab and 62.5% agreed after the third lab.

Table 6  
*Student Post-lab Survey on General Student Ability (N=15)*

The lab performed today helped to build my lab skills more than previous labs have done.			
	Post-lab #1 survey /number of respondents	Post-lab #2 survey /number of respondents	Post-lab #3 survey /number of respondents
Strongly disagree	1 (8.33%)	0 (0.0%)	0 (0.0%)
Somewhat disagree	0 (0.0%)	1 (11.1%)	1 (12.5%)
Neutral	1 (8.33%)	3 (33.3%)	2 (25.0%)
Somewhat agree	5 (41.7%)	2 (22.2%)	3 (37.5%)
Strongly agree	5 (41.7%)	3 (33.3%)	2 (25.0%)

The post-lab surveys' questions pertaining directly to the portion of the lab design that the students had to complete for that day's lab also showed a lower percentage of students agreeing that the intervention labs helping to develop the students in their laboratory skills (Table 7). The pattern was 75% agreeing prior to the first lab, 77.8% agreeing prior the second lab and only 62.5% agreeing prior to the third lab.

Table 7

*Student Post-lab Survey on Inquiry Student Ability (N=15)*

The exclusion of portions (that needed to be developed by the students) of the lab helped me to develop my skills in performing lab work.			
	Pre-lab #1 survey /number of respondents	Pre-lab #2 survey /number of respondents	Pre-lab #3 survey /number of respondents
Strongly disagree	0 (0.0%)	0 (0.0%)	0 (0.0%)
Somewhat disagree	0 (0.0%)	0 (0.0%)	0 (0.0%)
Neutral	3 (25.0%)	2 (22.2%)	3 (37.5%)
Somewhat agree	7 (58.3%)	6 (66.7%)	4 (50.0%)
Strongly agree	2 (16.7%)	1 (11.1%)	1 (12.5%)

Although the students felt that IB® Chemistry laboratory experiences helped to develop their skills, they were less in agreement about the three intervention labs. Even though more than half of the survey respondents agreed that the intervention labs helped to develop their laboratory skills, the percentage of students thinking that preparing for the intervention labs decreased for the third lab.

The post-lab student interviews showed that the students felt good about the first two labs but not so about the third lab. Overall, the students felt that the scaffolding labs, the enthalpy of neutralization lab and the Hess's Law lab, did a good job helping them to prepare for those labs as they had to develop different aspects for each lab while receiving the remaining parts of the lab. Receiving these remaining parts gave the students the means to develop the unknown sections. As one student responded during the interview, "not having these things [hypothesis, variable list, and material list] made us prepare more, understand better." After the second lab, a student stated that, "I think that it improved my understanding in the Hess's Law lab, I think that this lab is more effective than the first lab because the procedure is more important than the missing aspects from the first lab". This sentiment was not the same for the third lab. Since the students did not receive any sections for the third lab (the students only received the research question) the students felt overwhelmed and unprepared for the third lab so they did not put as much effort into designing the lab. An interviewee confirmed this by stating, "I don't think that it helped to prepare the lab since we just Googled it." A positive aspect that a student remarked on after the third lab was that although they felt they were unprepared for the third lab, they did feel that not receiving anything but the research question did help in writing the conclusion as they felt that they had a better understanding of hand-warmers and enthalpy changes of dissolution from researching the lab examples on the Internet.

#### Impact of Scaffolding on Student Confidence in Conducting Open Inquiry Lab

During all three intervention labs, there were two teachers present observing. One was the school's biology teacher and the other was myself. We observed all three labs, asking the students questions based on the focal points (Appendix E). Overall, the students seemed more prepared for these three intervention labs than they are for pre-intervention lab experiments.

The observational notes taken during the first lab showed that the students initially had trouble preparing for the lab. This was seen as the students developed material lists that were not suitable for the lab. Their material lists were either too little or too much. This showed that the students had trouble envisioning how they would conduct the lab and what materials they would need. With that being said, the students were observed to be more prepared for the lab than either teacher had seen with pre-intervention labs. The students were forced to think about the lab more as they had to develop the hypothesis. In developing the hypothesis, variable list and material list the students were nervous about interpreting the given procedure correctly. During the lab, however, students felt that they could interpret the procedure better as they were conducting it since they increased their understanding of how the collected data and procedure were related.

During the second lab, the teachers observed that students felt and acted less prepared for the lab than for the first lab since they had to develop their own procedure and data collection methods. The students were more worried about developing the procedure than developing the data collection method as they felt that the data collection method came more naturally to them than the procedure itself. Although the students

realized that the key to a good lab experiment is the procedure, as this determined the quality of the data collected, it was observed that none of the students made the connection that the needed data is what should drive the procedure design. During the course of the lab, the students' confidence improved as they were able to adapt their procedures to the hypothesis better in regards to unforeseen variables and conditions.

During the third lab, it was observed by the teachers, as well as described to them by the students, that the students were least prepared for this third lab than for the first two labs. Similar to the first two labs, as the third lab progressed, student confidence improved as they were better able to make connections between the hypothesis, variable list, procedure and the collected data.

The teachers' surveys conducted after each of the three labs showed that both teachers felt that the three labs generally helped to increase student confidence in conducting labs. The two teachers' surveys also showed that the exclusion of portions of each of the first two labs and the exclusion of the entire lab for the third lab also helped to increase the students' confidence in performing lab work.

There were two survey questions on the teacher's post-lab survey asking about increasing confidence in the students. The first one, 'The lab conducted today helped to build the students' confidence in conducting labs', received 100% agreement from the teachers for all three labs. The first lab received 50% somewhat agree and 50% strongly agree while both the second and third lab received 100% strongly agree in response to this question. The second question, 'The exclusion of these portions (different for each lab) of the lab helped the students to develop their confidence level in performing lab

work', also received 100% agreement from the teachers. The first two labs received a 50% somewhat agree and 50% strongly agree while the third lab received a 100% strongly agree.

Looking at the students' pre-lab and post-lab surveys, it can be seen that the three labs helped to improve the students' confidence towards conducting lab work. A pattern is seen in the pre-lab surveys as the percentage of respondents that disagreed that they are confident in conducting lab work decreases from 40.0% to 20.0% while the percentage of neutral increased by this same amount (Table 8). The percentage of respondents that agreed with being confident in conducting lab work stayed consistent ranging between 46.7% for the first and third labs and 42.9% for the second lab. When this is looked at in connection with the post-lab surveys' question, 'The lab performed today helped me to build my confidence in conducting labs more than previous labs have done', it can be seen that the students' increase in confidence can be connected to the three labs as all three labs saw the respondents answering with over 83% agreeing that the labs helped them develop their confidence in conducting labs (Table 9). The first lab saw 83.4% agree (41.7% somewhat and 41.7% strongly), the second lab saw 88.9% agree with 77.8% responding with somewhat and 11.1% strongly agreeing and the third lab saw 87.5% agree (62.5% somewhat and 25.0% strongly).

The post-lab interviews showed a similar attitude towards the three labs. After all three labs, the students answered that they felt more confident, that they were able to adapt the procedure during the lab, and that designing the portions of the lab (or the entire lab for the third experiment) was not as hard as they initially thought. Only one student

thought that it was more challenging than they initially thought. This was after the first lab, but by the second lab, this student answered that they felt more confident and that the design portion was not as hard. Another student reflected that “[I] could have done better

Table 8  
*Student Pre-lab Survey on General Student Confidence (N=15)*

In general, I am confident in conducting lab work in IB® Chemistry.			
	pre-lab #1 survey /number of respondents	pre-lab #2 survey /number of respondents	pre-lab #3 survey /number of respondents
Strongly disagree	1 (6.7%)	1 (7.1%)	1 (6.7%)
Somewhat disagree	5 (33.3%)	3 (21.4%)	2 (13.3%)
Neutral	2 (13.3%)	4 (28.5%)	5 (33.3%)
Somewhat agree	6 (40.0%)	6 (42.9%)	7 (46.7%)
Strongly agree	1 (6.7%)	0 (0%)	0 (0%)

Table 9  
*Student Post-lab Survey on General Student Confidence (N=15)*

The lab performed today helped to build my confidence in conducting labs more than previous labs have done.			
	post-lab #1 survey /number of respondents	post-lab #2 survey /number of respondents	post-lab #3 survey /number of respondents
Strongly disagree	1 (8.3%)	0 (0.0%)	0 (0.0%)
Somewhat disagree	0 (0.0%)	0 (0.0%)	1 (12.5%)
Neutral	1 (8.3%)	1 (11.1%)	0 (0.0%)
Somewhat agree	5 (41.7%)	7 (77.8%)	5 (62.5%)
Strongly agree	5 (41.7%)	1 (11.1%)	2 (25.0%)

with the material list, but the hypothesis was fine, the variables needed improvement as many items were left off, I feel that I can do better next time". There was an interesting comment at the end of the third lab interview as a student commented that they were worried about writing the report. During the other interviews, it came out that two other students were also worried about writing a full lab report on an open inquiry experiment. It seems that their confidence in designing and conducting the lab improved over the course of the three labs but the confidence in writing the lab reports did not see the same improvement in confidence.

#### Impact of Inquiry Labs on Student Attitude Towards Laboratory Work

In general, the students pre- and post-lab surveys showed that the students generally enjoy laboratory work in IB® Chemistry but their enjoyment of the inquiry laboratory work decreased during the three intervention labs. The three pre-lab surveys showed a positive shift in agreement regarding enjoyment as the percentages ranged from 47.0% before the first lab to 64.0% before the second and 60.0% before the third lab. This increase correlates with a negative shift in disagreement (Figure 1).

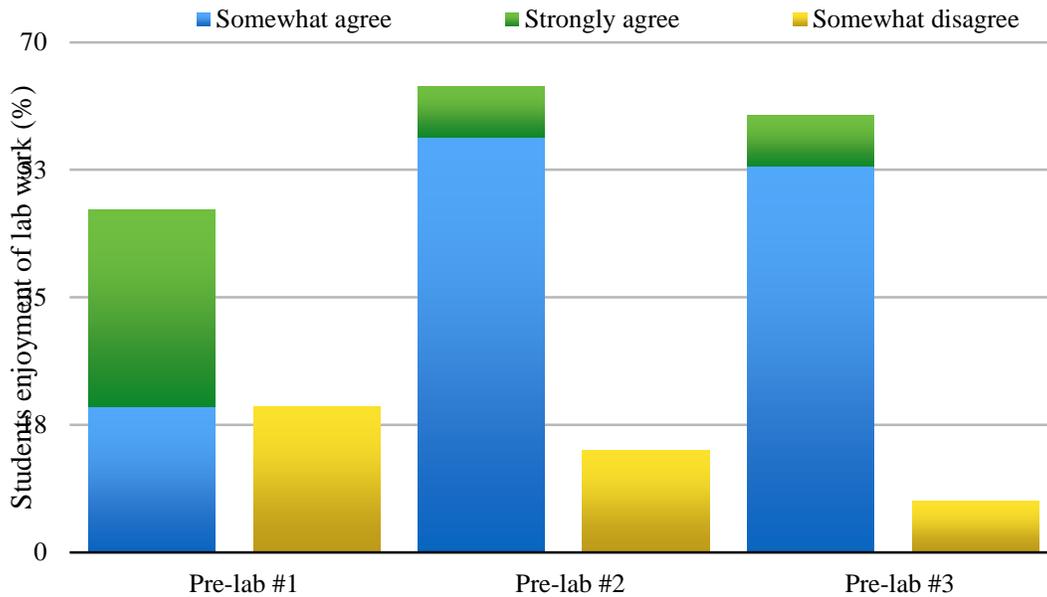


Figure 1. Pre-lab surveys showing the trend in student enjoyment, ( $N=15$ ).

The post-lab surveys asking specifically about that day's laboratory experiment showed a different pattern. In general, the percent that agreed that they enjoyed the day's lab decreased from the first lab through to the third lab (Figure 2). This was in conjunction with a negative shift in disagreement (Figure 3) and an increase for neutral responses (Figure 4). So, although the percentage of students responding with an increase in enjoyment decreased the percentage of students that responded with a decrease in enjoyment also decreased resulting in an increase in neutral responses

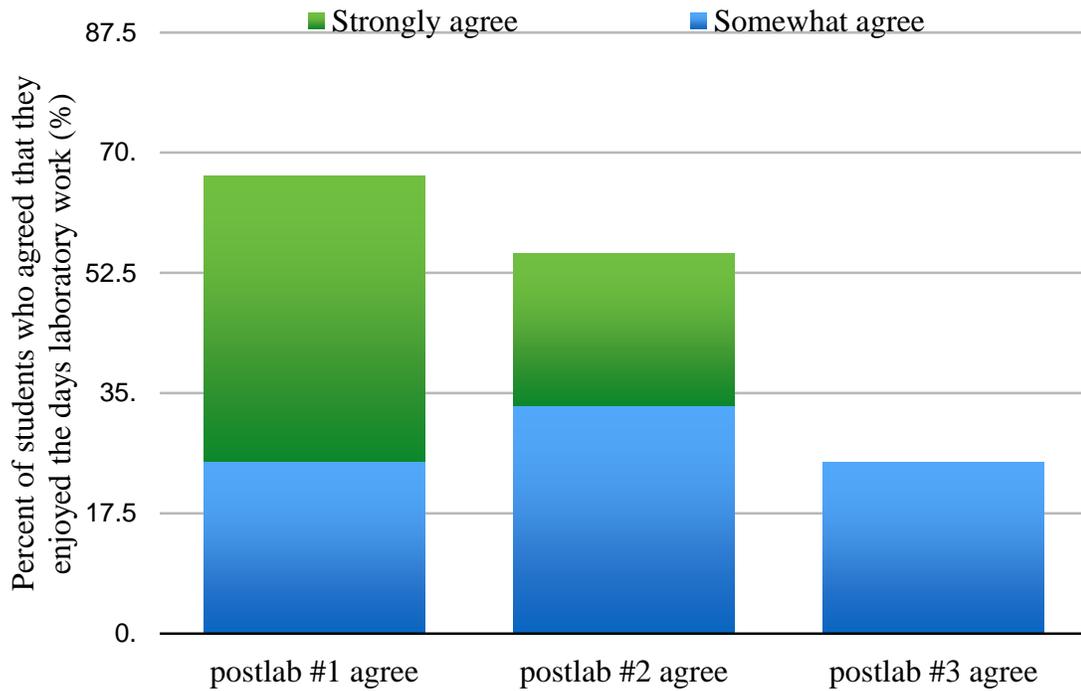


Figure 2. Post-lab Surveys showing agreement trend in student enjoyment, ( $N=15$ ).

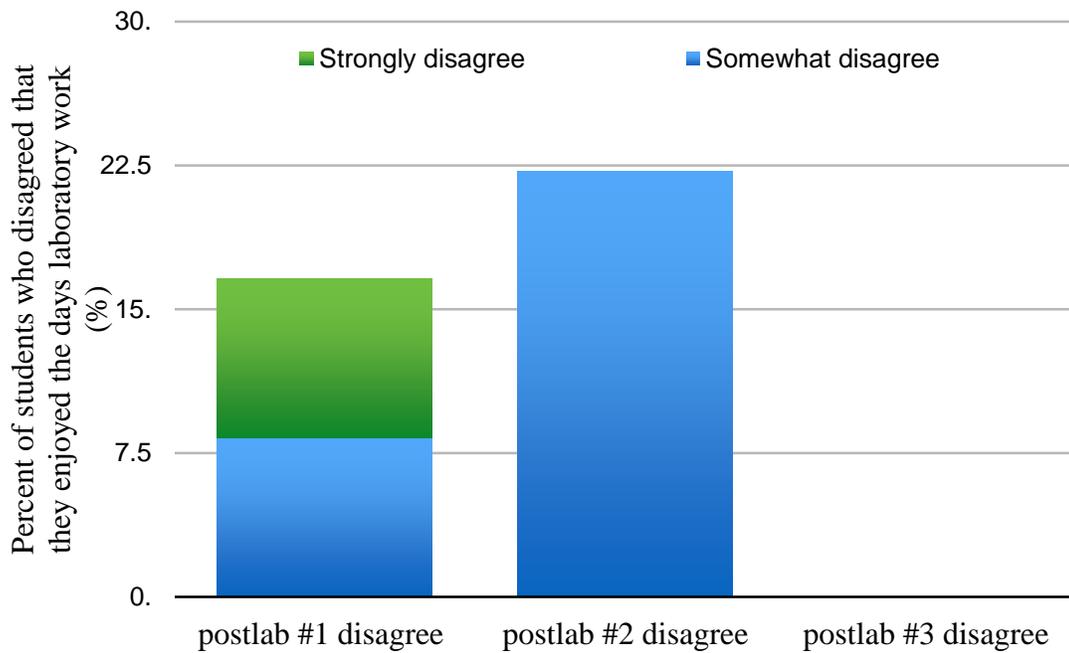


Figure 3. Post-lab surveys showing disagreement trend in student enjoyment, ( $N=15$ ).

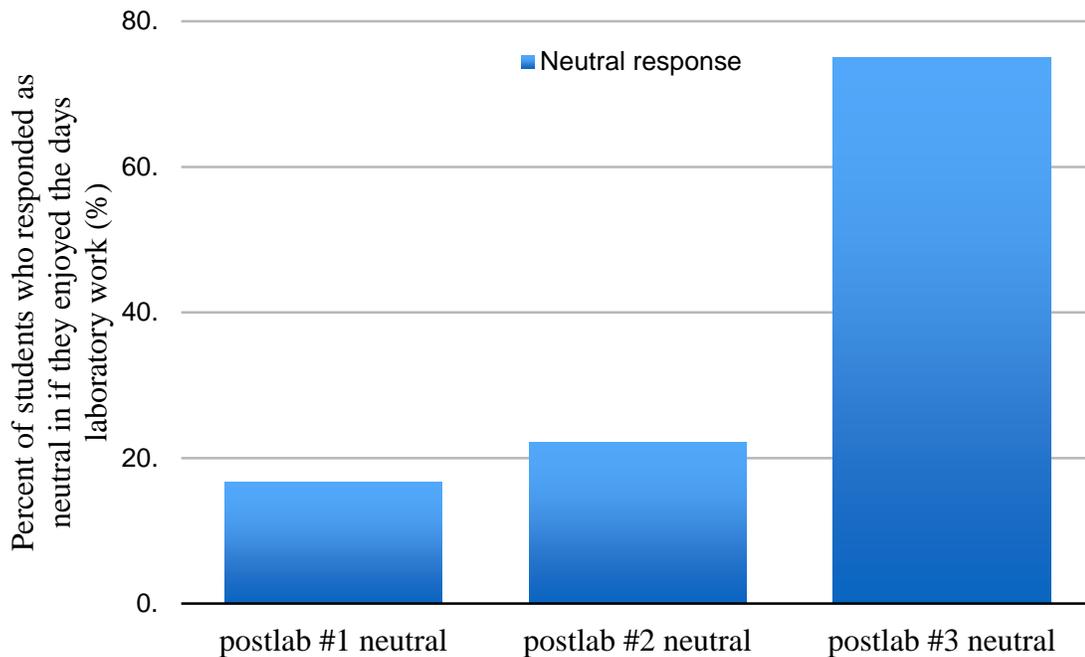


Figure 4. Post-lab surveys showing the neutral trend in student enjoyment, ( $N=15$ ).

According to the teachers' post-lab surveys, when prompted for the students enjoyment of the day's lab, both teachers agreed that the students enjoyed the day's lab for all three labs. When the data was broken down into somewhat agree against strongly agree, there was an increase from both teachers responding with somewhat agree for the first lab to both teachers responding strongly agree for the third lab. The second lab saw one somewhat agree response and one strongly agree response. So even though the students may not have thought that they enjoyed the lab, the teachers perceived them as enjoying the lab with that enjoyment increasing during the course of the intervention.

The student interviews went contradictory to the post-lab student surveys. The post-lab student surveys showed that the students enjoyed the labs less as the intervention progressed while the interviews showed that the students felt better during the course of

the intervention, that the students' attitude was positive during the intervention. After all three labs, the students responded during the interviews that they were feeling more confident, that it was not as hard as they thought it was going to be. After the second lab, the students remarked that it was getting easier to design the labs and after the third lab, a student remarked that they felt good about designing the lab. When asked to elaborate during the interview, the students replied that they felt that developing the portions of the lab and conducting the experiment was not as hard as they originally thought it would be. It was agreed upon that they felt that they should have done better and could do better next time.

#### Impact of Inquiry Labs on Student Ability in Analyzing Results

The ability to analyze the lab results was recorded as part of the lab reports that the students submitted. The students completed two lab reports where they were expected to analyze their data during the first term of the academic year (pre-intervention experiment 1 and pre-intervention experiment 2). The students also completed two lab reports during the intervention where they were expected to analyze their data (intervention experiment 2 and 3). All four of these lab reports were graded using the IB® IA chemistry rubric. The averages of the graded analysis section for the four lab reports improved between pre-intervention and intervention laboratory work (Table 10). The pre-intervention lab report analysis sections had class averages of 67.9% (SD=15.3) and 75.6% (SD = 11.0) while the two lab reports during the intervention had class averages for the analysis sections of 92.3% (SD = 11.0) and 85.9% (SD = 13.3). The lab

reports' scores showed that the students designing their own experiments resulted in the students being better able to analyze their data.

Table 10

*Comparison Between the Grades of Two Pre-intervention Labs, the Second Scaffolding Lab and the Open Inquiry Lab's Data Analysis (N=15)*

	Pre-Intervention Experiment 1 (%)	Pre-Intervention Experiment 2 (%)	Intervention Experiment 2 (%)	Intervention Experiment 3 (%)
Class average	67.9	75.6	92.3	85.9
Standard deviation	15.3	11.0	11.0	13.3

The students' interview responses show that during the intervention, a change in perception towards the interconnectedness of the different parts of the design and analysis was seen. After the first lab, the students were split on how connected the different parts of the design matched with the analysis. After writing the procedure for the second lab, the students saw the connection easier, stating that after writing the procedure, it was easier to analyze the data during the lab and they foresaw the writing of the analysis section of the report to be easier than before (pre-intervention). After the third lab experiment, the students again observed that they now saw the connection in what they designed and the data collected and how they were to analyze the data as one student stated, "I guess there is a connection, as the data that needs to be collected helps to write the procedure and the material list."

The teachers' observations painted a similar story of the students making the connection between the design aspects of the experiment and the analysis section, resulting in the students being able to analyze their data better. One teacher wrote down during his observation of the first lab that "the students understood that if the results did not relate to the hypothesis that they should revise the procedure or possibly the material list." During the second lab, one of the teacher observers remarked that "students realized that planning the procedure informs the material list and data collection. They tried to use the hypothesis to inform their procedures." During the third lab, this same teacher further saw the students making these connections when he wrote "during the experiment all the experimental portions were student driven. Because they were not given any one part, they were forced to interpret each section, not independently but in context of the others."

#### INTERPRETATION AND CONCLUSION

Students conducted three inquiry labs over seven weeks from January through the end of February. The first two labs were guided inquiry experiments and the third experiment was an open inquiry lab. The results of this intervention are mixed but with a generally positive shift.

The main finding from the data is that although scaffolding helped students to prepare for an open inquiry experiment, the amount of scaffolding used in this intervention was not sufficient. There tended to be an improvement of attitude towards lab work and data analysis from the first lab through to the third lab, although the change

between the first and second was greater than the change in attitude between the second and third labs.

Students and teacher observers commented several times that the scaffolding helped the students prepare for the open inquiry laboratory experiment. The results of the lab reports showed that even though the students were better prepared, they did not do so well in communicating their analysis when comparing the third experiment to the second experiment. When comparing the intervention labs to the pre-intervention labs, the students did much better in analyzing their data. The post-lab student surveys showed that the students felt more prepared for the first two labs than for the third lab. Looking at all the data, it can be concluded that the scaffolding labs helped the students to feel more prepared, to better handle the labs than the third open inquiry lab did. The third lab appears to be too much of a jump in too short of a time after the two scaffolding labs.

Scaffolding helped the students to make connections within the laboratory experience. When asked by the teacher observers about how different components of the laboratory experience fit together, the students were able to clearly explain. This ability to make connections strengthened as the intervention progressed. The literature does not directly refer to connections within the inquiry lab between the different aspects of the lab but rather, alludes to the interconnectedness of the process. McMurtry (1988) refers to the underlying connections of inquiry while the NRC (2102) discusses following scientists' methods and that many different methods can be used. Scientists' methods include the scientific process of questioning, researching, hypothesizing, experimenting, analyzing and communicating. Being able to make the connections within the scientific

process is part of inquiry. The students were making these connections with understanding of how one affected another. The students were also adapting and modifying their experiment as errors appeared showing that they realized that they did not need to stick to one method of completing the experiment.

During the first intervention lab, the students were able to explain the connection between the hypothesis and procedure, procedure and the materials and variables lists. One student replied during the interview after the first lab that “yes, initially I really did not care about the connection between volume and heat change, but writing the hypothesis made me realize that volume is not the sole factor that affects temperature change, but is just one of several factors”.

During the intervention, the students were able to make the connection between the various parts of the lab experience. As one of the teacher observers noted that a student explained “procedure allows for the testing of the hypothesis and that the procedure leads to data collection which leads to analysis”. These are connections that I have never heard explained by the students, connections that the students clearly understood and not just stated from memory.

Even though scaffolding helped the students make better connections within the laboratory experiment, the attitude towards open inquiry and the ability of the student to communicate their findings and analysis did not make the same improvement. Both of these aspects decreased when compared to the second laboratory experiment of the intervention. The literature agrees with the greater positive attitude towards guided inquiry when compared with open inquiry. According to a study done by Chatterjee,

Williamson, McCann, and Peck (2009), students were more positive towards guided inquiry over open inquiry. The student participants felt the same way. They felt more confident towards the first two experiments and felt that these two guided experiments were more enjoyable than the open inquiry lab. This more positive attitude toward the scaffolding labs (guided inquiry labs) was seen during all three labs. During the first two labs the students came into the labs more prepared, more confident, knowing what to do and how to do it. During the third labs, the students were unsure of their procedures and data collection methods. This was observed by the teachers and by the students as reported in their post-lab surveys.

The open inquiry lab was performed too soon and without enough scaffolding labs prior. If the students had received more lab experiments to develop the various aspects of the inquiry process, I feel that the students would have had a better experience with the open inquiry experiment.

The next steps for continuing the development of my intervention is to develop a better scaffolding plan that incorporates more labs to help prepare the students for open inquiry. I have a set of recommendations that I feel would work well in developing the students for an open inquiry lab that uses the findings of this study. These recommendations are for developing the students over a two-year period that coincides with the length of time for the IB diploma program. There are five parts to this recommendation that I would like to suggest.

The first part of the recommendation is to start year one of the program (grade eleven) with an open inquiry lab that is completed as a large group incorporating the

entire class and teacher. In the large group, each aspect of the open inquiry lab should be discussed and agreed upon as a class leading to a lab experiment that the students conduct. Discussing and conducting the experiment will show how each of the parts connect and how to complete an open inquiry experiment. The results can be presented in front of the class with an open discussion for the analysis and conclusion. This discussion can be recorded and made available to the students as a resource for future experiments.

The second part is to do several guided inquiry lab experiments as small groups. These guided inquiry experiments should focus on one or two aspects of the design process per experiment. The results, analysis, and conclusion can be a group presentation with feedback from the students and teachers.

The third part is for the students to complete a full open inquiry experiment at the end of grade eleven in small groups. Given a research question based on the material being learned, the small groups should design the lab in its entirety. The report should be typed up and submitted to the teacher for practice in writing their data, analysis, and conclusion. The report can be completed as a group and submitted electronically using a program such as Google Docs that allows for the teacher to see who and to what extent they participated in writing the report.

The fourth part is for a research question to be given to the students at the end of grade eleven. The students should be placed in groups consisting of pairs of students. The pair is to design a lab experiment over the summer, using what they have learned from the guided and open inquiry labs during the year and present their design at the

beginning of grade twelve. The students will conduct the lab according to their design and submit a group written lab report.

The fifth part is for the students to develop guided inquiry experiments focusing on their weakest aspects. The students can be paired so that students with similar weaknesses are either in the same group or in different groups. In the same groups will allow the students to work together through their weakness developing each other. If the groups include a mix of weaknesses then a student with a strength in an aspect can help those with a weakness.

I feel that if the scaffolding process could be extended over the entire first year of IB lab work (grade 11), then an open inquiry experiment with teacher feedback could be performed at the end of the first year. This would give the students a chance to see how much their open inquiry skills have improved during the year when compared to the first one they did at the beginning of the school year. First term of the second year would have the students doing final preparations for their IB internal assessment that would take place during the beginning of the second term. Hopefully, by this point the students will have become proficient in open inquiry labs and do well on their internal assessment for IB.

To answer the focus question “how does a scaffolding approach to student controlled (open) inquiry lab affect the students’ experience in a chemistry laboratory?”, I would have to conclude positively if there is enough scaffolding to develop the students to a point where the students can be successful in the open inquiry lab. I would think that conducting multiple guided labs focusing on different aspects and different groupings of

aspects would be most beneficial. It is important to develop the students' confidence in their ability to design the experiment if the students are going to be able to conduct an open inquiry lab successfully.

#### VALUE

This project has impacted my teaching as I want to include more inquiry activities, not just labs but classroom activities as well as it was observed by both teacher observers that the students were more engaged. The students also alluded to this in the surveys and interviews as they talked about being better at adapting the procedure and data collection methods to the experiences in the laboratory. I think a natural progression for this project is to expand it to inquiry based classroom activities and not limited to lab experiments. So a future project could be how to scaffold guided inquiry classroom activities to best prepare students for open inquiry activities.

The action research process has impacted my perceptions of professional learning and growth by showing me that a scientific study can be done to improve my teaching. Normally, I attend workshops where I might take away a few ideas that may or may not be incorporated into my classroom. The action research project that I conducted on inquiry was completely about my classroom and how I teach. This project has shown that I can now go to those workshops, get an idea, do some research and implement an intervention that is for my classroom. This project has shown me the way to take another person's ideas and find out if it can work for me and my classroom.

Inquiry in the chemistry laboratory is becoming standard in many schools. The push for inquiry chemistry laboratory experiments by IB® and AP® is what brought

inquiry labs into my school's chemistry laboratory. The main conclusion that I am taking away from this experience is that using scaffolding experiments develop the students for an open inquiry but more scaffolding is needed than what was provided during this intervention. The students enjoyed the scaffolding labs more than the open inquiry lab, they also were able to analyze their data better after the two scaffolding labs than they were able to do for the open inquiry lab and they had greater confidence during the two scaffolding labs. I feel that if more scaffolding labs were implemented then the open inquiry lab would have been met with a more positive attitude. I feel this because the students were not prepared enough for the open inquiry lab and this is why the students had a less positive attitude, less confidence and were able to analyze their data to a lower degree.

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APPENDICES

APPENDIX A  
PRE-LAB STUDENT SURVEYS

## Pre-lab survey

Please check the box that best applies, then answer the question at the bottom of the survey. Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at any time.

	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
In general, I enjoy laboratory work in IB® Chemistry.					
In general, I am confident in conducting lab work in IB® Chemistry.					
I think that laboratory work in IB® Chemistry helps me to understand the topics that are learned in class.					
I think that laboratory work in IB® Chemistry helps me to learn laboratory skills.					
I understand the goals, objectives, and the data that is to be collected for the lab that is being performed today.					
I understand how to perform today's lab.					
I understand the safety concerns of today's lab.					
What do you think is the biggest weakness of laboratory work in IB® Chemistry?					
What do you think is the biggest strength of laboratory work in IB® Chemistry?					

APPENDIX B  
POST-LAB STUDENT SURVEYS

Post-lab #1: Heat Capacity of Water

Please check the box that best applies, then answer the question at the bottom of the survey. Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at any time.

	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
The lab performed today helped to build my lab skills more than previous labs have done.					
The lab performed today helped to build my concept understanding more than previous labs have done.					
The lab performed today helped to build my confidence in conducting labs more than previous labs have done.					
In today's lab, I was not given a hypothesis, variables, and the material list. I found it difficult to develop these on my own.					
The exclusion of these portions of the lab helped me to develop my skills in performing lab work.					

The exclusion of these portions of the lab helped me to develop concept understanding of energetics.					
The exclusion of these portions of the lab help me to develop my confidence level in performing lab work.					
Today's lab has increased my enjoyment of laboratory work in IB® Chemistry.					
I have a better understanding of how the hypothesis, variables, and the material list fit into the laboratory design.					
What was the biggest weakness of today's lab?					
What was the most challenging part of today's lab?					

## Post-lab #2: Enthalpy of Neutralization

Please check the box that best applies, then answer the question at the bottom of the survey. Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at any time.

	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
The lab performed today helped to build my lab skills more than previous labs have done.					
The lab performed today helped to build my concept understanding more than previous labs have done.					
The lab performed today helped to build my confidence in conducting labs more than previous labs have done.					
In today's lab, I was not given the procedure and data collection methods. I found it difficult to develop these on my own.					
The exclusion of these portions of the lab helped me to develop my skills in performing lab work.					

The exclusion of these portions of the lab helped me to develop concept understanding of energetics.					
The exclusion of these portions of the lab help me to develop my confidence level in performing lab work.					
Today's lab has increased my enjoyment of laboratory work in IB® Chemistry.					
I have a better understanding how the procedure and data collection methods fit into the laboratory design.					
What was the biggest weakness of today's lab?					
What was the most challenging part of today's lab?					

Post-lab #3: Hand-warmer challenge

Please check the box that best applies, then answer the question at the bottom of the survey. Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at any time.

	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
The lab performed today helped to build my lab skills more than previous labs have done.					
The lab performed today helped to build my concept understanding more than previous labs have done.					
The lab performed today helped to build my confidence in conducting labs more than previous labs have done.					
In today's lab, I was not given the hypothesis, variables, material list, procedure, and data collection methods. I found it difficult to develop these on my own.					
The exclusion of these portions of the lab helped me to develop my skills in performing lab work.					

The exclusion of these portions of the lab helped me to develop concept understanding of energetics.					
The exclusion of these portions of the lab help me to develop my confidence level in performing lab work.					
Today's lab has increased my enjoyment of laboratory work in IB® Chemistry.					
I have a better understanding how the procedure and data collection methods fit into the laboratory design.					
What was the biggest weakness of today's lab?					
What was the most challenging part of today's lab?					

APPENDIX C  
POST-LAB TEACHER SURVEYS

## Post-lab #1: Heat Capacity of Water

Please check the box that best applies, then answer the question at the bottom of the survey. Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at any time.

	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
The lab performed today helped to build the students' lab skills.					
The lab performed today helped to build the students' concept understanding.					
The lab performed today helped to build the students' confidence in conducting labs.					
In today's lab, the hypothesis, variables, and material list were not given. The students found it difficult to develop these on their own.					
The exclusion of these portions of the lab helped the students to develop their skills in performing lab work.					
The exclusion of these portions of the lab helped the students to develop concept understanding of energetics.					

The exclusion of these portions of the lab help the students to develop their confidence level in performing lab work.					
The students enjoyed today's lab.					
The students have a better understanding how the hypothesis, variables, and the material list fit into the laboratory design.					
What was the biggest weakness of today's lab?					
What was the most challenging part of today's lab?					

## Post-lab #2: Enthalpy of Neutralization

Please check the box that best applies, then answer the question at the bottom of the survey. Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at any time.

	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
The lab performed today helped to build the students' lab skills.					
The lab performed today helped to build the students' concept understanding.					
The lab performed today helped to build the students' confidence in conducting labs.					
In today's lab, the procedure and data collection methods were not given. The students found it difficult to develop these on their own.					
The exclusion of these portions of the lab helped the students to develop their skills in performing lab work.					
The exclusion of these portions of the lab helped the students to develop concept understanding of energetics.					

The exclusion of these portions of the lab help the students to develop their confidence level in performing lab work.					
The students enjoyed today's lab.					
The students have a better understanding how the hypothesis, variables, and the material list fit into the laboratory design.					
What was the biggest weakness of today's lab?					
What was the most challenging part of today's lab?					

## Post-lab #3: Hand-warmer challenge

Please check the box that best applies, then answer the question at the bottom of the survey. Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at any time.

	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
The lab performed today helped to build the students' lab skills.					
The lab performed today helped to build the students' concept understanding.					
The lab performed today helped to build the students' confidence in conducting labs.					
In today's lab, the hypothesis, variables, material list, procedure, and data collection methods were not given. The students found it difficult to develop these on their own.					
The exclusion of these portions of the lab helped the students to develop their skills in performing lab work.					
The exclusion of these portions of the lab helped the students to develop concept understanding of energetics.					

The exclusion of these portions of the lab help the students to develop their confidence level in performing lab work.					
The students enjoyed today's lab.					
The students have a better understanding how the hypothesis, variables, and the material list fit into the laboratory design.					
What was the biggest weakness of today's lab?					
What was the most challenging part of today's lab?					

APPENDIX D

POST-LAB STUDENT INTERVIEW QUESTIONS

### Post-lab #1: Heat Capacity of Water

Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at any time.

1. What were your initial thoughts concerning not being given the hypothesis, variables and material list?
2. How do you feel now that you have completed the lab using the hypothesis, variables and material list that you developed?
3. How do you think not being given these things developed your ability to be prepared for the lab, perform the lab and complete the lab report?
4. Is there a connection between developing the hypothesis, variables and material list and understanding the concepts covered by the lab and in class?
5. If you were to do the lab again, developing your own hypothesis, variables and material list, what would you do differently and/or the same?

### Post-lab #2: Enthalpy of Neutralization

Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at any time.

1. What were your initial thoughts concerning not being given the procedure and data collection methods?
2. How do you feel now that you have completed the lab using the procedure and data collection methods that you developed?
3. How do you think not being given these things developed your ability to be prepared for the lab, perform the lab and complete the lab report?
4. Is there a connection between developing the procedure and data collection methods and understanding the concepts covered by the lab and in class?
5. If you were to do the lab again, developing your own procedure and data collection methods, what would you do differently and/or the same?

### Post-lab #3: Hand-warmer challenge

Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at any time.

1. What were your initial thoughts concerning not being given the hypothesis, variables, material list, procedure, and data collection methods?
2. How do you feel now that you have completed the lab using the hypothesis, variables, material list, procedure, and data collection methods that you developed?
3. How do you think not being given these things developed your ability to be prepared for the lab, perform the lab and complete the lab report?
4. Is there a connection between developing the hypothesis, variables, material list, procedure, and data collection methods and understanding the concepts covered by the lab and in class?

5. If you were to do the lab again, developing your own hypothesis, variables, material list, procedure, and data collection methods, what would you do differently and/or the same?

APPENDIX E  
TEACHER OBSERVATION FOCAL POINTS

Focal points for the teacher observers.

1. Comment on how prepared the students seem to be during the lab.
2. Comment on how on task the students stayed.
3. Comment on how confident the students seemed during the lab.
4. Comment on connections that student make between the hypothesis, variables, materials, procedure and data collection.
5. Further comments on observations.

APPENDIX F

IB® INTERNAL ASSESSMENT RUBRICS (2014)

## Exploration

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1-2	<p>The topic of the investigation is identified and a research question of some relevance is stated but it is not focused.</p> <p>The background information provided for the investigation is superficial or of limited relevance and does not aid the understanding of the context of the investigation.</p> <p>The methodology of the investigation is only appropriate to address the research question to a very limited extent since it takes into consideration few of the significant factors that may influence the relevance, reliability and sufficiency of the collected data.</p> <p>The report shows evidence of limited awareness of the significant safety, ethical or environmental issues that are relevant to the methodology of the investigation.</p>
3-4	<p>The topic of the investigation is identified and a relevant but not fully focused research question is described.</p> <p>The background information provided for the investigation is mainly appropriate and relevant and aids the understanding of the context of the investigation.</p> <p>The methodology of the investigation is mainly appropriate to address the research question but has limitations since it takes into consideration only some of the significant factors that may influence the relevance, reliability and sufficiency of the collected data.</p> <p>The report shows evidence of some awareness of the significant safety, ethical or environmental issues that are relevant to the methodology of the investigation.</p>
5-6	<p>The topic of the investigation is identified and a relevant and fully focused research question is clearly described.</p> <p>The background information provided for the investigation is entirely appropriate and relevant and enhances the understanding of the context of the investigation.</p> <p>The methodology of the investigation is highly appropriate to address the research question because it takes into consideration all, or nearly all, of the significant factors that may influence the relevance, reliability and sufficiency of the collected data.</p> <p>The report shows evidence of full awareness of the significant safety, ethical or environmental issues that are relevant to the methodology of the investigation.</p>

## Analysis

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1-2	<p>The report includes insufficient relevant raw data to support a valid conclusion to the research question.</p> <p>Some basic data processing is carried out but is either too inaccurate or too insufficient to lead to a valid conclusion.</p> <p>The report shows evidence of little consideration of the impact of measurement uncertainty on the analysis.</p> <p>The processed data is incorrectly or insufficiently interpreted so that the conclusion is invalid or very incomplete.</p>
3-4	<p>The report includes relevant but incomplete quantitative and qualitative raw data that could support a simple or partially valid conclusion to the research question.</p> <p>Appropriate and sufficient data processing is carried out that could lead to a broadly valid conclusion but there are significant inaccuracies and inconsistencies in the processing.</p> <p>The report shows evidence of some consideration of the impact of measurement uncertainty on the analysis.</p> <p>The processed data is interpreted so that a broadly valid but incomplete or limited conclusion to the research question can be deduced.</p>
5-6	<p>The report includes sufficient relevant quantitative and qualitative raw data that could support a detailed and valid conclusion to the research question.</p> <p>Appropriate and sufficient data processing is carried out with the accuracy required to enable a conclusion to the research question to be drawn that is fully consistent with the experimental data.</p> <p>The report shows evidence of full and appropriate consideration of the impact of measurement uncertainty on the analysis.</p> <p>The processed data is correctly interpreted so that a completely valid and detailed conclusion to the research question can be deduced.</p>

## Evaluation

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1-2	<p>A conclusion is outlined which is not relevant to the research question or is not supported by the data presented.</p> <p>The conclusion makes superficial comparison to the accepted scientific context.</p> <p>Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are outlined but are restricted to an account of the practical or procedural issues faced.</p> <p>The student has outlined very few realistic and relevant suggestions for the improvement and extension of the investigation.</p>
3-4	<p>A conclusion is described which is relevant to the research question and supported by the data presented.</p> <p>A conclusion is described which makes some relevant comparison to the accepted scientific context.</p> <p>Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are described and provide evidence of some awareness of the methodological issues* involved in establishing the conclusion.</p> <p>The student has described some realistic and relevant suggestions for the improvement and extension of the investigation.</p>

5-6	<p>A detailed conclusion is described and justified which is entirely relevant to the research question and fully supported by the data presented.</p> <p>A conclusion is correctly described and justified through relevant comparison to the accepted scientific context.</p> <p>Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are discussed and provide evidence of a clear understanding of the methodological issues* involved in establishing the conclusion.</p> <p>The student has discussed realistic and relevant suggestions for the improvement and extension of the investigation.</p>
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APPENDIX G  
IRB APPROVAL FORM



**INSTITUTIONAL REVIEW BOARD**  
**For the Protection of Human Subjects**  
**FWA 00000165**

960 Technology Blvd, Room 127  
 c/o Immunology & Infectious Diseases  
 Montana State University  
 Bozeman, MT 59719  
 Telephone: 406-994-6783  
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*Chair:* Mark Quinn  
 406-994-5721  
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*Administrator:*  
 Cheryl Johnson  
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**MEMORANDUM**

**TO:** Daniel Betts and Eric Brunzell  
**FROM:** Mark Quinn, Chair *Mark Quinn (H)*  
**DATE:** November 17, 2014  
**RE:** "Does Scaffolding Help to Improve the Open Inquiry Experience for High School Students?" [DB111714-EX]

The above research, described in your submission of November 17, 2014, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

- (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
- (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.
- (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.
- (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.
- (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.
- (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.