

Implementing Inquiry Based Learning into a High School Science Classroom

By

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Abstract

In an inquiry based classroom students are challenged to create knowledge and develop models to understand the world around them. They are asked to engage in the same activities that mathematicians, engineers, and scientists are engaged in every day: to wonder and question, hypothesize and conclude, investigate and analyze. The purpose of this Curriculum Development Project was to use Inquiry Based Learning (IBL) to help students to acquire science content knowledge at or above previous levels, improve student knowledge in the processes of inquiry, and increase student engagement in and overall appreciation of science.

Implementing Inquiry Based Learning into a High School Science Classroom

Literature Review

The call for more Inquiry Based Learning (IBL) has been a long one, but for many reasons, the implementation has been almost negligible. It will be shown that prominent science educators and national organizations have spent a century trying to convince schools and educators to adopt IBL. Goals and standards have been clearly defined, studies have been conducted, curricula have been designed, textbooks have been rewritten, yet very few students are actually involved in inquiry based learning in the classroom. First, the history of IBL and the scientific efficacy of IBL will be presented, and then some of the reasons adoption has been so abysmal.

History

Early Proponents. The history of IBL shows a consistent theme of promoting student centered instruction, where students tackle relevant problems, propose solutions, and design research to test hypotheses. As early as 1910 John Dewey was one of the first to call for a change in science instruction in America. According to Barrow (2006), science instruction, as with all instruction in early American schools, relied heavily on textbooks. In his article *A Brief History of Inquiry: From Dewey to Standards*, Lloyd Barrow wrote “Dewey considered that there was too much emphasis on facts without enough emphasis on science for thinking and an attitude of the mind” (Barrow, 2006, pp. 265-266). Dewey wanted teachers to use inquiry as a teaching strategy, holding students to the scientific method, with teachers becoming more of a facilitator, guiding students to a personal knowledge of science (Barrow, 2006). Barrow noted, “Dewey’s model was the basis for the Commission on Secondary School Curriculum (1937) entitled *Science in Secondary Education*” (2006, p. 266).

Throughout the 1950's and 1960's many educators, such as Joseph Schwab, supported Dewey's beliefs. As cited in Barrow, Schwab authored many papers (1958, 1960, 1962, & 1966) including *Enquiry*, *The Science Teacher*, and *The Educator* in 1960 and *The Teaching of Science as Enquiry* in 1966 (2006, p. 266). Barrow concludes, "Schwab believed that, students should be given the opportunity to view science as a series of conceptual structures that should continually be revised when new information or evidence is discovered" (2006, p. 266). This belief models the accepted structure of science by scientists themselves. Schwab's goal was to see science students and teachers operate like real scientists (Barrow, 2006).

National Attention. The call for IBL was reignited after the launch of the first artificial satellite, Sputnik I, by the Soviet Union in 1957. At the 1959 Woods Hole Conference, one of the two goals for the development of science curriculum was to teach scientific inquiry rather than a large array of facts. Students were to be engaged in hands-on activities designed to teach scientific measurement, hypothesis testing, and data analysis (Pea, 2008, pp. 4-5). For the first time, with funding from the National Science Foundation (NSF), many new science curricula were developed implementing IBL, along with funding for professional development to implement them. The emphasis was on thinking like a scientist and on scientific processes (Barrow, 2006).

The NSF sponsored many projects including a literature review covering 1955 to 1975, case studies, and a national survey, which were compiled and published as Project Synthesis in 1981. IBL was one of five areas chosen to be studied in the project. Another major development implemented at that time was called Project 2061 which, according to their website is, "A long-term American Association for the Advancement of Science (AAAS) initiative to advance literacy in Science, Mathematics, and Technology" (AAAS - Project 2061, 2012). Project 2061, "identified what all students should know and be able to do when they graduate at the end of

12th grade” (Barrow, 2006, p. 267). Their first document, which was originally published in 1989, *Science for All Americans*, stated, “Taken together, these values, attitudes, and skills can be thought of as habits of mind because they all relate directly to a person's outlook on knowledge and learning and ways of thinking and acting” (Ahlgren, 2012, Habits of Mind, para. 3). Project 2061 was advocating the same ideas as Dewey eighty years earlier, that science education should be about students doing science rather than learning about science as a world separate from their own.

In the overview of the 1996 National Science Education Standards (NSES), developed by the National Research Council (NRC) it states, “Inquiry is central to science learning. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others” (National Committee on Science Education Standards and Assessment, 1996, p. 11). The NSES concluded that IBL is central to science learning and stated what that inquiry based learning should look like.

The call for educators to use IBL has been a long one, especially more recently from national science organizations. And this call has been consistent in trying to get science students doing the very things scientists do. However, this call has been ignored by most teachers, so the approach more recently has been focused on proving the efficacy of IBL.

Efficacy

In this age of accountability teachers must be assured that when changing to a new pedagogical model that student ability to acquire content knowledge does not decrease. In response to this concern many studies have been conducted to evaluate the efficacy of IBL and it has been shown to maintain or increase student content knowledge in science.

Another Synthesis Project, supported by an NSF grant, was released in 2010 synthesizing data from 1984 through 2002 to try to answer the question, “What is the impact of inquiry science instruction on K-12 student outcomes” (Minner, Levy, & Century, 2010, p. 474). The authors concluded, “This overall finding indicates that having students actively think about and participate in the investigation process increases their science conceptual learning” (Minner, Levy, & Century, 2010, p. 494).

In a study entitled, *Performance of Students in Project-Based Science Classrooms on a National Measure of Science Achievement*, researchers looked at 10th and 11th graders who had been taught using Project Based Science (PBS), a form of IBL, for 2 and 3 years respectively. These students took the 1996 12th grade National Assessment of Educational Progress (NAEP) science test and significantly outscored the national average on 44% of the test items while only scoring significantly lower on 14% of the test items. The greatest difference was found for the extended constructed response questions where the PBS students significantly outscored the national average on 75% of the questions. This would suggest a deeper understanding of science content and greater scientific literacy. Schneider, et al. concluded, “This study shows that educators need not fear that students in inquiry-based science courses will be disadvantaged on large-scale achievement tests. PBS students performed as well or better on almost all of the items used to make comparisons...” (Schneider, Krajcik, Marx, & Soloway, 2002, p. 420).

In their study, *The Relative Effects of Inquiry-Based and Commonplace Science Teaching on Students’ Knowledge, Reasoning and Argumentation about Sleep Concepts: A Randomized Control Trial* (Wilson, Taylor, Kowalski, & Carlson, 2009) researchers were responding to criticism of IBL by cognitive architecture theorists. Cognitive architecture theorists maintain that IBL, what Paul Kirschner calls minimal guidance instruction, cannot increase learning because it violates the accepted understanding of how we learn. Kirschner argues that students

don't have the long term memory to be able to draw conclusions on their own (Kirschner, 2006). In other words, because they are not experts in science, they cannot be expected to draw scientific conclusions. Kirschner concludes there is no evidence from controlled scientific studies supporting minimal guidance instruction (Kirschner, 2006, p. 83). However, Wilson found, "using scientifically-based research methods that meet the standards required by the evidence-based reform movement to establish causality" (Wilson, Taylor, Kowalski, & Carlson, 2009, p. 5) that students in an IBL classroom significantly outperformed students taught by the same master instructor, but receiving commonplace teaching.

"The superior effectiveness of the inquiry-based instruction was consistent across a range of learning goals (knowledge, scientific reasoning, and argumentation) and types of measures (dichotomous items, open-response items, and clinical interviews). This study therefore contributes to the growing body of evidence demonstrating the effectiveness of inquiry-based teaching." (Wilson, et. al, 2009, p. 5)

They go on to conclude,

"Since students in the inquiry-based group outperformed students receiving commonplace instruction on each of the knowledge, scientific reasoning, and argumentation measures, this study provides evidence that teachers need not compromise the quality of their teaching to see increases in student achievement in an age of accountability" (Wilson, et. al, 2009, p. 5).

Kirschner, the cognitive theorist, mistakenly makes the assumption that minimal guidance means very little guidance or no guidance. Minimal guidance means giving appropriate guidance, but only as needed, for students to reach the intended outcomes. Kirschner is right, in that, hands-on activities alone are not enough. In an article on Supported Inquiry Science (SIS) researchers found that gains on posttests for the SIS students were almost double the gains for

Activities Based Science students, pointing to the importance of minimally guided instruction (Dalton, Morocco, Tivnan, & Mead, 1997). Hands-on activities are not enough, discovery must be guided by instructors and student's minds must be engaged in the process to effect learning in an inquiry classroom.

In a meta-analysis study conducted on research from 1965 to 1985, researchers looked at eight different alternative teaching strategies, including IBL, and found all eight to have a significant effect on student achievement. Kevin Wise stated,

"Students experiencing the alternative strategies perform better on various science achievement tests than students receiving traditional science instruction... is there a feature that characterizes the alternative strategies and distinguishes them from traditional strategies for teaching science? The answer is yes: Inquiry-oriented instruction. Inquiry strategies involve students in the use of thinking skills in order to gain new knowledge (Birnie and Ryan 1984). Although the inquiry category contains only strategies that were called inquiry or discovery by the researchers, it is clear that inquiry-type strategies pervade and define the other seven categories as well." (Wise, 1996, p. 338)

He went on to conclude, "On the basis of this analysis of the research, we recommend that teachers use inquiry strategies as the predominant approach to science instruction in middle and secondary schools" (Wise, 1996).

In a similar meta-analysis done on research from 1980 to 2004, evaluating the effectiveness of the same eight alternative teaching strategies researchers noted, "If students are placed in an environment in which they can actively connect the instruction to their interests and present understandings and have an opportunity to experience collaborative scientific inquiry under the guidance of an effective teacher, achievement will be accelerated" (Schroeder, Scott, Tolson, Huang, & Lee, 2007, p. 1452).

IBL has been proposed as a superior method for students to learn science for a century, has been supported by national science organizations for over 50 years, and more recently research using large scale achievement tests, randomized control trials, and meta-analyses all confirm that IBL is superior to traditional teaching in terms of student achievement.

Lack of Implementation

Despite these facts, IBL is not the norm in classrooms. In their 2009 report on the efficacy of inquiry Wilson states "... it is nevertheless surprising that such a sustained and largely consistent drive for reform has had such little impact on teacher practice" (2009, p. 1).

In another 2009 study a survey was conducted on 1,222 teachers to determine their beliefs and use of inquiry in their classrooms. Science teachers reported that on average they devote 37.3% of their time to inquiry during typical lessons; high school science teachers self-evaluated at a lower 28.5% (Marshall, Horton, Igo, & Switzer, 2009). In another study, cited in Wilson, using "classroom observations and interviews with 364 science and mathematics teachers, Weiss et al. (2003) found that inquiry was a focus of only 2% of science lessons in grades 9-12". The Weiss study was done earlier and could indicate a move towards more IBL instruction in classrooms, but a recent study done by Bodzin and Beerer showed that most educators cannot self-evaluate their level of inquiry even when given a rubric to use (see Appendix A). So, the 28.5% number in the Marshall study is most likely inflated, because Bodzin and Beerer concluded that educators do not always have a clear understanding of what inquiry is and what it should look like in the classroom. The study though did confirm that when the same rubric was used by trained observers, the rubric had a correlation of 1 (Bodzin & Beerer, 2003). While there have been subtle moves, and pockets of success, most science classrooms today are entrenched in rote memorization and cookie cutter labs, where students gain little knowledge of, or appreciation for the study of science and how it applies to their lives. Unfortunately, worse

than that, there are many educators that think they are using inquiry based strategies, when in fact they are not.

Reasons for lack of implementation. There are many reasons IBL is not common place in classrooms. Based on the studies above one reason is because of the lack of pedagogical knowledge as to what IBL means. “The meaning of the term inquiry-based instruction when applied to classroom practice often becomes muddled, and the integrity of the inquiry-based instruction can be lost” (Crawford, 2000, p. 918). Teachers may even think they are using an inquiry based program, but in the end, it may no longer resemble inquiry.

The most often cited reasons for the lack of implementation of IBL are: content-driven state documents and textbooks, lack of support and preparation for teachers, and the ease of teaching and assessing content focused instruction (Welch, Klopfer, Aikenhead, & Robinson, 1981), (Eltinge & Roberts, 1993). Ronald Anderson grouped the barriers and dilemmas in to three dimensions; Technical, Political, and Cultural, which sheds more light into the complexity of this problem.

The technical dimension included limited ability to teach constructively, prior commitments (e.g. to a textbook), the challenges of assessment, difficulties of group work, the challenges of new teacher roles, the challenges of new student roles, and inadequate in-service education. The political dimension included limited in-service education (i.e., not sustained for a sufficient number of years), parental resistance, unresolved conflicts among teachers, lack of resources, and differing judgments about justice and fairness. The cultural dimension—possibly the most important because beliefs and values are so central to it—included the textbook issue again, views of assessment and the “preparation ethic,” i.e., an overriding commitment to “coverage” because of a perceived need to prepare students for the next level of schooling. (Anderson, 2002, p. 8)

These challenges cannot be resolved by just adopting new standards or curriculum. There needs to be a cultural change in the way we view science and science education and this educator believes this change can only come about by teachers themselves implementing IBL in the classroom and showing how successful students can be using an inquiry based approach. But, if teachers are unclear as to what an IBL classroom looks like how do we get them to effectively implement it?

In their study, *The Effects of Professional Development on Science Teaching Practices and Classroom Culture*, researchers found that, “[b]oth teaching practices and classroom cultures were affected most deeply after intensive and sustained staff development activities... the big change in teaching practice came after 80 h of professional development, while the big change in investigative culture came only after 160 h” (Supovitz & Turner, 2000, pp. 975-976). While previous studies found that professional development had little impact on science teaching practices Supovitz and Turner noted that most of those previous studies were based on staff development that was shorter in length and intensity (Supovitz & Turner, 2000).

The push for IBL in schools has been a long one, especially most recently by national science organizations; and the efficacy of IBL has been proven, but will the reasons for lack of implementation continue to haunt this movement, or can the promise of the Next Generation Science Standards and its implementation of inquiry as a central theme within each standard be the catalyst to cause IBL to become a common sight in our class rooms? For this educator it is clear that the implementation of IBL is necessary.

Justification for the Development of this Project

It is often said that we teach the way we were taught. But, transformation is a key element in success, and as humans we have the ability to transform ourselves. We have the

ability to do what is right despite our own personal tendencies to do what we want. This project is the start of that transformation for this teacher.

Personal Justification

Personally, I came to realize that inquiry or investigation is what I love about science. It's the exciting part of science, and when I look back at my science education it was always the investigation and its associated challenge that I found the most exhilarating. And I also found I was becoming tired of teaching the same subject, the same way, with just adequate results. So, I began to look at those lessons which I felt had the greatest impact on my students and began to evaluate what it was about those lessons which so engaged my students.

One lesson was a physical science lesson on gravitational acceleration that was greatly modified in my second year of teaching. I was demonstrating how all objects accelerate towards the earth at the same rate regardless of their mass, resulting in them landing at the same time if simultaneously released at the same height. I was standing on the ground and many students in the back could not see, so I climbed up on the demonstration table and had the objects land on the table. I had used two different massed balls of the same size and the students started asking me to try other things, so I did, and we concluded that all things don't accelerate towards the earth at the same rate. A complete opposite result to the statement I had written on the board just previous to the demonstration. This was most obvious when we "raced" a book and a flat sheet of paper. The book landed with a bang on the table as the paper slowly settled to the floor. Fortunately, I saw this as an opportunity to extend the conversation and asked, "Would it be possible to cause them to fall at the same rate?" After a few trials the students were able to get the book and the sheet of paper to fall at the same rate, causing them to burst into applause at their accomplishment. It was after this experience that I began to recognize that in an effort to simplify science, so students can understand it, we often make statements that are counter to their

own observations of the world. We cannot change a student's concept of the world, unless we can give them concrete evidence on which to change that concept.

The complimentary questioning and discussion on air resistance, friction, surface area, and density was the most focused interest I had experienced as a teacher up to that point. I began to extend this activity to have student groups try to get the paper to fall at the same rate as the book on their own, and return to show everyone their solution and results. Now, I also challenge them to see which group can cause the sheet of paper to fall in the greatest amount of time (maximize air resistance) and the least amount of time (minimize air resistance). I encourage groups to try multiple ideas, record data, and come up with their best design. It was during this process that I concluded that students love to do research when it is answering questions that they have, or when they are challenged to design something to solve a problem.

I used to think IBL took too long and couldn't cover enough subject matter in the time I had with students, and would just be too chaotic. But, I came to realize it was necessary to engage students and to teach the inquiry process. I have seen too many students, often the most capable students; get to the point where they will literally say, "Just tell me what I need to know for the test". I needed to make this change, so that I could feel better about the quality of learning going on in my classroom. I want my students to understand the process of gaining new knowledge, not just list the steps. I want students to become critical thinkers, engaged in learning a process that will guide them to becoming more scientifically literate.

I previously used text book driven, lecture based, instruction, with teacher directed confirmation labs, and mostly traditional formal assessments. This project was significantly different in that I reduced lecture time, increased lab time, and incorporated nontraditional assessments. But within those structural changes was a more important change from a teacher centered to a student centered approach to learning. All of these changes were needed for

inquiry to be successful in my classroom. Although this was becoming a stronger personal choice, unknown to me at the time, it was also becoming a requirement placed upon me as science educator.

Meeting District, State, and National Goals

In the 1996 NSES the word inquiry was used 247 times, 115 times in the science content standards alone, of which *Science as Inquiry* is one of the content standards, but it is clear that science inquiry is not just another topic to be taught, but it is, "... basic to science education and a controlling principle in the ultimate organization and selection of students' activities."

(National Committee on Science Education Standards and Assessment, 1996, p. 105). The NRC felt strongly that this was a new vision for science education to have, "... students combine processes and scientific knowledge as they use scientific reasoning and critical thinking to develop their understanding of science" (National Committee on Science Education Standards and Assessment, 1996, p. 105).

The Wisconsin Model Academic Standards for Science were adapted from the NSES in 1998 and in their introduction state, "Students and teachers are encouraged to work together by using inquiry methods each day of class instruction" (Wisconsin Department of Public Instruction, 2009). Glenwood City High School (GCHS) has adopted the Wisconsin Model Academic Standards for Science, but also has 14 *Attributes of a GCHS Graduate* which inquiry learning can help develop, especially the attributes of: Collaborative, Perseverance, Critical thinking, Knowledgeable, and Lifelong Learner (Glenwood City High School, 2012). The goal of national organizations, such as the NRC, the NSTA, the American Association of Physics Teachers, and the American Chemical Society, also the Wisconsin Department of Public Instruction, and the School District of Glenwood City is to incorporate inquiry instruction into

science classrooms.

Design of the Curriculum Development Project

The goal of this curriculum development project was to begin the transformation of a classroom from a traditional lecture and confirmation lab classroom to an inquiry based classroom. To accomplish this lecture time was reduced and laboratory time was increased, but more importantly laboratory expectations needed to be changed drastically.

Using the Science Teacher Inquiry Rubric (STIR) (Bodzin & Beerer, 2003, pp. 43-44, Figure 1) original labs were evaluated for their level of inquiry and then the labs were either modified to increase their level of inquiry or replaced completely. The STIR can be used by science educators or administrators to determine the level of inquiry in a classroom on a scale from Learner Centered to Teacher Centered. The more learner-centered the instruction the more inquiry strategies are being used (see appendix A). The rubric evaluates six categories based on the *Essential Features of Classroom Inquiry* defined by the NRC (2000). The six categories are: Engaging with a scientifically oriented question, Planning investigations, Giving priority to evidence, Formulating explanations from evidence, Connecting explanations to scientific knowledge, and, Communicating and justifying explanations. Original labs were scored a four if completely learner centered down to a one if completely teacher centered, or given a zero if that category was not present in the lab. Therefore, the total possible for a completely learner centered lab activity was a 24.

For example, a lab on reaction rates (see appendix B) scored a seven out of 24, because the original lab defined the topic, the question, and the hypothesis for the students. It also defined the variables, and listed the materials and procedures to be used. It prescribed what to measure and how to measure it, including a data table to be filled in with labeled headings.

Questions directed students to specific data to lead them to the predetermined “correct” answers, and, there was no communication of ideas. Basically, it was a fill in the blank worksheet that kept them busy for a while. Very little knowledge was gained, especially in the processes of inquiry.

In contrast the modified version (see appendix C) required students to develop their own question and hypothesis, gave students options as to what reaction they would be using and what variables they would be testing. Required students to list the materials needed, and be specific about how they were going to modify the basic procedure including how they were going to vary their independent variable. Data was taken and recorded on a data table created by the students. They graphed their data and were asked to evaluate their own data with no prompting questions (which was interesting since some of the data was inconsistent). And, finally, each group wrote a lab report supporting their conclusions and adding discussion for further investigation.

The modified version of the lab scored 18 out of 24 on the STIR, which was significantly better. Because this was a ninth grade physical science class that had never been exposed to an inquiry lab the topic for investigation was chosen for them, and basic procedures were given for each reaction, which reduced the score for those two areas. Not having much practice, students also needed a lot of prompting when it came to analyzing the evidence, and identifying alternative explanations that reflected scientific understanding, especially when unexpected results occurred.

This was a tremendous improvement over the original lab, and similar results were attained in two other units. The Reactivity Series Lab was modified by having students write their own procedures, removing data tables, and removing questions that led students to predetermined conclusions. These and other smaller changes also improved its STIR score from

an 8 to 18 out of 24. This lab is also for a ninth grade chemistry class so choices about the topic, data collection, and communication were decided by the instructor.

The Colligative Properties Lab was improved by completely rewriting the lab from the perspective of, “is this a decision the students could make on their own?” The goal being to make this lab as learner centered as possible. This improved the lab from an 8 to 24 out of 24. This was possible, because it was a lab for junior chemistry students, where it was felt they could handle more freedom towards the end of the year. In each lab there was an increase in student participation and questioning. The increased time in lab allowed for groups to redo investigations or do extensions to answer more questions. And the deeper knowledge gained, not only in the content covered, but in the processes and skills scientists use was evident.

Results

As shown in the table below, out of the five labs scored using the STIR rubric the average was a 9.8 point increase in scores. This demonstrates a 41% increase towards learner centered lab activities. The largest increase in scores was 15 points on the Colligative Properties Lab and the smallest increases of 7 and 8 coming from two previously modified labs that were also improved upon. The average score for the modified labs was 20.2 out of 24 with the lowest score being 18 out of 24 and the highest score being 24 out of 24.

Lab Name	Initial STIR Score	Final STIR Score	Increase in Score
Acceleration Due to Gravity Lab	15	22	7
Alternative Fuels Research Lab	12	20	8
Colligative Properties Lab	8	23	15
Reaction Rates Lab	9	18	9
Reactivity Series Lab	8	18	10
Average	10.40	20.20	9.80

Table 1: STIR Rubric Scores

Personal Observations

Focusing on learner centered labs was an important change, but the increased time in the laboratory was also an important procedural change that was made. Because students were figuring things out on their own, many labs had to be redone. It was a great relief to students when they found out they could redo a lab the next day. Many even enjoyed the challenge of redoing a lab to see if they could get better results. The ability to redo a lab gave them a chance to perfect their technique, try new ideas, and change their procedure. This extra time also allowed for some students to do further inquiry, many students would even stop in after school or during study hall to check on their labs. The increased time in the laboratory had many positive effects on increased inquiry process knowledge and student engagement.

But the greatest change came in the form of great student questions and a corresponding increase in the number of times I said yes to the question, “Can we try...?” In an inquiry based classroom students have the freedom to ask questions, in fact it becomes essential. When there is no procedure, then the students are expected to come up with the answers to a multitude of questions. Instead of being given the answers (steps in the process), students have to think, solve problems, and come up with a way to make it work, just like real scientists. They experience the defeat of a failed experiment, but also the excitement of a successful flight. Inquiry puts the challenge back in the science classroom and my students were more engaged in the learning process than I had ever seen.

Concerns. However, there were a few students who found the change to be to challenging. It was stressful for some students to not have a procedure to check. A few didn’t like it when I would tell them, “Try it and see what happens”, only to watch it fail. But, these students had never been exposed to inquiry to this extent and had become dependent upon notes and memorization. I did have two junior chemistry students complain in their lab reports that it

would have been easier if they had been given procedures to follow, not realizing that having them develop the procedures on their own gave them the opportunity to gain a deeper knowledge of the subject and the techniques required to study it.

Student Perceptions

This curriculum project was focused on two sections of ninth grade physical science which included 55 students, but some of the general conclusions are based on changes also made in chemistry and physics classrooms, which included 22 and 6 students, respectively. An end of class discussion was done for each physical science class. Students were asked, on a scale of zero to ten, which labs they preferred, Inquiry Based labs (zero) or Confirmation labs (ten). Throughout the course the two types of labs were presented as alternative lab types. It was never suggested that one was better than the other, just that they were different ways to go about learning new information. Students were reminded of examples of the two lab types and then asked the question; “If you could choose one of these lab types or a combination of the two, what would be the best way for you to learn science?” It was explained to the students that choosing a one would mean they would want to do inquiry based labs all of the time, choosing a ten would mean they would want to do confirmation labs all of the time, and choosing a number in between would represent a combination of the two types of labs. The mean for both classes was 3.4 ± 2.9 , the students preferred inquiry based labs over confirmation labs. 83% chose a five or below, and 30% chose a zero or a one, meaning they would want inquiry based labs all the time, or almost all of the time. But, as Norman Reid (2006) pointed out, trying to quantify attitudes in science is a historically difficult thing to do because of the problems of scaling, correlation, and loss of detail. These inherent problems make it important to give students an opportunity to comment through open ended questions. Without knowing why respondents chose the number they did, the numbers become meaningless.

Therefore, later in a classroom discussion, students were asked what they liked and disliked about each type of lab. Comments were written on the board and then grouped by common themes, and are displayed below in Table 1. When taking a look at their comments, what students liked about the inquiry based labs are the types of things we want them to like about labs: to have the freedom to choose their investigation, to learn more, and have new experiences with materials and processes. Choosing their own investigation allows students to have some investment in the process. Making it their own created more of an urgency to do well. Students recognized that writing down their own conclusions based on evidence they gathered caused them to learn more. Students also realized that the knowledge gained came not only within the concept, but also in the processes needed to learn the concept.

When taking a look at what students didn't like about confirmation labs, it is exactly what we don't want from a lab: for it to be easy, with less thinking, and for it to be possible for students to cheat. Confirmation labs are easier because, as the students pointed out as a dislike for confirmation labs, they already know the answer. Students will manipulate their data to get the "right answer" not realizing their data was wrong, because they were performing the lab incorrectly. With a confirmation lab a lab group could potentially not do the lab at all, or do it incorrectly and still be able to score well if they have all of the blanks filled in correctly. Unfortunately, in this scenario, many students do not get a better understanding of the concepts being taught and do not improve their scientific process skills. Through this discussion the students, on their own, caught on to one of the most powerful aspects of IBL that students can learn more and have more fun doing it.

Student Comments on Inquiry Based Labs		Student Comments on Confirmation labs	
Liked	Disliked	Liked	Disliked
• More freedom ○ Independence ○ “It was like you gave us a student Bill of Rights” ○ Trusted us with chemicals • More learning ○ More writing ○ Found out things ourselves ○ Made us think more • Got to use new stuff ○ Chemicals ○ Apparatus	• Didn’t know what to do ○ No idea ○ Not enough details • Lab partners didn’t help • No checking with other labs	• Step-by-step ○ Easier ○ Less thinking ○ All set up • Took less time • No lab report (only had to answer questions) • Everyone gets the same answer ○ Can cheat ○ Can check	• Knew what was going to happen ○ No surprise • Step-by-step can be frustrating ○ Starting over ○ Not enough time • Less freedom

Table 2: Lab Likes and Dislikes

Based on the responses in the discussion it appears that students know which lab type is better for their learning, but it was discovered in an even later discussion, with just a few students, that some students probably moved their answer to the original question towards the confirmation labs because they would prefer to do the “easier” labs. Perhaps thinking their input would influence future decisions about the labs in which they would participate. If this is true then the numbers submitted here would be falsely skewed towards the confirmation labs.

But there is a concern here, some students disliked inquiry labs, because they felt lost and didn’t know what to do. There are students who are less confident, or worry if they are doing things the right way and inquiry based learning can make them feel uncomfortable. Care needs to be taken to identify these students and give them the support they need individually, and within the context of a group setting.

Reflection

Although my Masters of Science Education courses offered many hands-on and real world lab experiences and allowed me to see labs as needing to take a more prominent role in my classroom, most of those lab experiences were not inquiry based, or if they were the contrast between inquiry and confirmation labs was not clearly stated. Not having the personal experience of what an inquiry based high school classroom looks like did make it difficult to begin the transition to an inquiry based classroom. In looking at professional development researchers have concluded "...high quality professional development must immerse participants in inquiry, questioning, and experimentation and therefore model inquiry forms of teaching", and, "...reformers argue that professional development must be both intensive and sustained" (Supovitz & Turner, 2000, p. 964). While I was introduced to inquiry in my undergraduate techniques courses it was never intensive or sustained enough to convince me of its necessity. It was only through the frustration of a traditional classroom that I was able to begin looking to an alternative classroom style to what I was already doing.

My search for answers started with a belief in constructivism which originated through a study of the work of Piaget during my undergraduate education courses. A strong belief that knowledge is constructed by successively building up structures or models of understanding, one upon another, set me on an inevitable course towards IBL. Later, finding Dewey's comments on having less emphasis on facts and more emphasis on an attitude of mind, struck a chord with me. If we are concerned about constructing models to better understand the world around us, then complicated word structures can get in the way of learning scientific content, especially for younger students.

For the Future

In the laboratory, I would like to add a peer review process to labs that include a final written report, so students have the opportunity to evaluate others' work and improve their own technical writing skills. Also, I want to be more aware of students with low confidence or ability levels, to make sure they are well supported, including giving lab groups the tools to support those students, by having clearer lab roles and fostering more planning and organization before starting a lab.

I also intend to continue to more fully implement IBL into my classroom by continuing to improve lab experiences and by adding more project based assessments. I also plan to use journal writing as a way to promote curiosity and engagement in laboratory work (Towndrow, Ling, & Venthan, 2008). I will push for more professional development in IBL for our district and will engage administrators in a discussion of a school wide IBL science program.

Knowing that IBL can increase student content knowledge, improves knowledge in the processes of inquiry, and increases student engagement in and overall appreciation of science gives me the confidence to develop a science program based on a foundation of IBL and to be an advocate for IBL in my district, region, and state. The imminent release of the Next Generation Science Standards has already sparked great discussion, and again will hopefully be a catalyst for great changes towards more IBL in science education.

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Appendix A

Science Teacher Inquiry Rubric (STIR)

Directions: Reflect on the science lesson that you taught today. In your reflection, consider each of the following categories and the six statements on the left, written in bold. After looking at each bold statement, assess today's science instruction based on the categories delineated for statement. Place one "X" in the corresponding cell for each bold-faced statement. If there is no evidence of one of the statements in today's lesson, place a slash through the bold-faced statement. When you are finished, you should have 6 total responses.

Learner Centered			Teacher Centered		
Learners are engaged by scientifically oriented questions.	Teacher provides an opportunity for learners to engage with a scientifically oriented question.	Learner is prompted to formulate own questions or hypotheses to be tested.	Teacher suggests topic areas or provides samples to help learners formulate own questions or hypotheses.	Teacher offers learners lists of questions or hypotheses from which to select.	Teacher provides learners with specific stated (or implied) questions or hypotheses to be investigated.
☐	☐	☐	☐	☐	☐
Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.	Teacher engages learners in planning investigations to gather evidence in response to questions.	Learners develop procedures and protocols to independently plan and conduct a full investigation.	Teacher encourages learners to plan and conduct a full investigation, providing support and scaffolding with making decisions.	Teacher provides guidelines for learners to plan and conduct part of an investigation. Some choices are made by the learners.	Teacher provides the procedures and protocols for the students to conduct the investigation.
☐	☐	☐	☐	☐	☐
Teacher helps learners give priority to evidence which allows them to draw conclusions and/or develop and evaluate explanations that address scientifically oriented questions.	Learners determine what constitutes evidence and develop procedures and protocols for gathering and analyzing relevant data (as appropriate).	Teacher directs learners to collect certain data, or only provides portion of needed data. Often provides protocols for data collection.	Teacher provides data and asks learners to analyze.	Teacher provides data and gives specific direction on how data is to be analyzed.	No evidence observed.
☐	☐	☐	☐	☐	☐

Learners formulate explanations and conclusions from evidence to address scientifically-oriented questions.						
Learners formulate conclusions and/or explanations from evidence to address scientifically-oriented questions.	Learner is prompted to analyze evidence (often in the form of data) and formulate own conclusions/explanations.	☐	Teacher prompts learners to think about how analyzed evidence leads to conclusions/explanations, but does not cite specific evidence.	☐	Teacher directs learners' attention (often through questions) to specific pieces of analyzed evidence (often in the form of data) to lead learners to predetermined correct conclusion/explanation (verification).	No evidence observed
Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.	Learner is prompted to examine other resources and make connections and/or explanations independently.	☐	Teacher provides resources to relevant scientific knowledge that may help identify alternative conclusions and/or explanations. Teacher may or may not direct learners to examine these resources, however.	☐	Teacher does not provide resources to help learners formulate alternative conclusions and/or explanations. Instead, the teacher identifies related scientific knowledge that could lead to such alternatives, or suggests possible connections to such alternatives.	No evidence observed
Learners communicate and justify their proposed explanations and justify their proposed conclusions and/or explanations.	Learners specify content and layout to be used to communicate and justify their conclusions and explanations.	☐	Teacher talks about how to improve communication, but does not suggest content or layout.	☐	Teacher specifies possible content to include and/or layout that might be used.	No evidence observed

Appendix B

Rates of an Antacid Reaction Lab

Introduction

An antacid contains all of the ingredients needed for this lab. When the tablet is placed in water citric acid ($\text{H}_3\text{C}_6\text{H}_5\text{O}_7$) reacts with the base, sodium bicarbonate (NaHCO_3), to give carbon dioxide, water, and a salt (sodium citrate). The tablet, therefore, provides a nice chemical package that can be used to carry out reaction rate experiments.

Temperature is one of many factors that affect the rate at which a chemical reaction occurs. Collision theory states that as temperature increases, the particles in a reaction move faster, resulting in a higher frequency of collisions and increased kinetic energy in each collision. Other variables affect reaction rates as well. In this investigation, you will examine the effect of temperature on the rate of reaction of an antacid tablet in water. After performing this investigation, you will report on how your results fit with your understanding of collision theory and rates of reaction.

Problem

Which factors affect the rate of the antacid reaction?

Materials

Chemical splash goggles
Laboratory apron
Tap water, hot and cold
Shallow pan or trough
Gas-collecting bottles, 500-mL
Ice

Thermometer
Glass square or piece of posterboard
Antacid tablets
Stopwatch or clock with a second hand
Glass marking pen
Graduated cylinder, 100-mL

Safety

Wear goggles and lab apron at all times during the investigation. Do not ingest the antacid tablet. Ingestion of undissolved antacid tablets causes gas pains and can lead to a herniated stomach. Handle hot water with care to avoid burns. Use hot pads or tongs when handling hot objects.

Procedure

1. Put on your goggles and lab apron. Place about 3 cm of tap water in the bottom of a pan or trough. Fill the bottle to the brim with ice-cold water. Record the temperature in the Data Table.
2. Place a glass square over the mouth of the bottle and hold it tightly. Invert the bottle, and place it mouth-down into the pan of tap water. Remove your hand and the glass square. Some water may run from the gas-collecting bottle into the pan.
3. Remove an antacid tablet from its package. Get ready to time the reaction by watching the clock or readying the stopwatch.
4. When the person who is timing gives the signal, tilt the gas-collecting bottle slightly and slip the tablet under the mouth of the bottle. Do not lift the mouth of the bottle above the surface of the water in the pan.
5. Time the reaction until the last bit of tablet stops fizzing. Record the time for the reaction in the Data Table.
6. Measure the volume of gas given off as follows: Mark the gas/water line of the bottle with a glass marking pen. Remove the bottle from the pan, let the water run out, invert the bottle, and fill it with water to the mark. Measure the volume of this water using a graduated cylinder. (You may have to fill the cylinder more than once). Record the volume.

7. Rinse any antacid residue from the bottle. Repeat Steps 1-6 with bottles filled with water adjusted to 10°C, 20°C, 30°C, and 40°C. Adjust tap water to 10°C with ice. Make the temperature of the water 30°C and 40°C by combining hot and cold tap water. Continue to record your observations in the Data Table.
8. Flush leftover solutions down the drain with excess water. Clean up your work area and wash your hands before leaving the laboratory.

Observations

DATA TABLE: Effect of Temperature on Reaction Rate			
Temperature (°C)	Time (s)	CO ₂ (cm ³)	Reaction Rate (cm ³ /s)
0			
10			
20			
30			
40			

Analysis and Conclusions

Questions

1. Construct a graph of the reaction time vs. temperature and the CO₂ volume vs. temperature.
2. How does a change in temperature affect reaction time and CO₂ volume?
3. How did the rate of the reaction vary with the temperature of the water?

Appendix C

*Reaction Rate Experiment****Initial Plan***

Name: _____

Objective: to design an experiment that explores one way to change the rate of a chemical reaction.

What reaction do you want to experiment with? Predict and write the reaction that will occur.

- | | |
|---|---|
| ☐ H_2O_2 decomposition | ☐ $\text{Zn} + \text{HCl}$ |
| ☐ $\text{Fe} + \text{CuSO}_4$ | ☐ $\text{CaCl}_2 + \text{NaHCO}_3$ |
| ☐ $\text{Al} + \text{CuCl}_2$ | ☐ $\text{HCl} + \text{CaCO}_3$ |
| ☐ $\text{Zn} + \text{CuSO}_4$ | ☐ Vinegar + Baking Soda |
| ☐ $\text{Mg} + \text{HCl}$ | |

Which of the four reaction rate factors do you want to investigate?

- ☐ Changing the concentration of one of the reactants
- ☐ Changing the surface area of one of the reactants
- ☐ Changing the temperature of the reaction
- ☐ Experimenting with a catalyst for the reaction

Discuss possible ways you could change your independent variable below.

Describe your dependent variable, and how you are going to measure it.

List other factors you will need to control throughout the experiment.

Materials & Equipment List: Please check everything you can get/find yourself, I will get the rest.

☐ _____	☐ _____
☐ _____	☐ _____
☐ _____	☐ _____
☐ _____	☐ _____

Appendix D

Freezing Point Depression and Boiling Point Elevation Lab

Purpose: In this experiment you will investigate the effect that adding a solute has on the boiling and freezing points of a solvent.

Background: When a solute is dissolved in a solvent, the properties of the solvent are changed by the presence of the solute. The magnitude of the change generally is proportional to the number of moles of solute added per kilogram of solvent (molality). Colligative properties of a solution are those properties of a solvent that are changed only by the number of solute particles present, without regard to the particular nature of the solute. These properties include changes in vapor pressure, the boiling point, and the freezing point. When a solute is added to a solvent, the amount of solvent that can escape from the surface of the solution at a given temperature is lowered, relative to the amount of particles that can escape from the pure solvent. Therefore, the vapor pressure above such a solution will be lower than the vapor pressure above of the pure solvent under the same conditions. Molecules of the solute physically block the surface of the solvent, thereby preventing as many solvent molecules from evaporating at a given temperature. The presence of a solute lowers the temperature at which the solution freezes and raises the temperature at which the solution boils relative to the pure solvent.

Materials:

100ml Graduated Cylinder	Thermometer	Ring Stand and Ring
150ml Beaker	Stirring Rod	Clamp
250ml Beaker	Wire Gauze	Bunsen Burner & Striker
Crushed Ice	Distilled Water	Sugar (Sucrose)
Salt (Sodium Chloride)	Calcium Chloride	Slotted Rubber Stopper

Procedure: Freezing Point Depression

1. Because of the difficulties that would be involved in trying to weigh a sample of ice accurately, we will be making only a “semi-quantitative” study of freezing point lowering.
2. Weigh out separately the following samples for use in the freezing point study: 34.2g of sucrose, 58.84g of sodium chloride, and 11.0g of calcium chloride. Each of these samples represents 0.1mol of the respective substance.
3. Fill the 150mL beaker with ~100ml crushed ice, packing the ice as tightly as possible in the beaker. Add 25.0mL of distilled water to each beaker. By adding the liquid water, we are constructing the solid-liquid equilibrium system, whose temperature should be exactly 0°C as long as any ice is present in the system. Although we do not know the exact mass of water (both ice and liquid) in the beaker, we can assume that the total amount in beaker is very nearly 100ml.
4. Determine the temperature of the ice/water mixture. Make certain that the thermometer is held in the middle of the ice/water mixture and does not touch the walls or bottom of the beaker. Note if the temperature as read on your thermometer differs from 0°C. Keep this error in mind when reading the temperatures of the experimental solutions during the rest of this experiment.

5. Add the weighed sample of sucrose to the 150mL beaker containing the ice/water mixture. Stir the sugar with a stirring rod until it dissolves as much as possible. Then determine the temperature of the ice/water/sugar mixture. Record the value after making any adjustments based on error noted when measuring the temperature of the ice/water mixture prior to adding the solute.
6. Repeat the process using fresh ice/water with the sodium chloride and then again with the calcium chloride sample in place of the sucrose. Record the freezing point temperature of the mixture after making any adjustments based on error noted when measuring the temperature of the ice/water mixture prior to adding the solute.

Procedure: Boiling Point Elevation

1. Set up an apparatus for boiling (ring stand, ring, wire gauze, clamp, slotted rubber stopper, and thermometer). Set up the thermometer so that the temperatures above 100 ° C can be easily read. Make sure the thermometer can be supported in the middle of the liquid being heated, and that it is not resting on the bottom of the beaker in contact with the burner flame.
2. Weigh out separately the following samples for use in the boiling point study: 34.2g of sucrose, 5.84g of sodium chloride, and 11.0g of calcium chloride. Each of these samples represents 0.1mol of the respective substance.
3. With your graduated cylinder, measure out exactly 100mL of distilled water and transfer to the 250 beaker. Begin heating the water and bring it to a gentle boil.
4. When the water is gently boiling, determine its temperature. The boiling point of water varies with atmospheric pressure, but should be very near 100 ° C. Note if the temperature as read on your thermometer differs from 100°C. Keep this error in mind when reading the temperatures of the experimental solutions during the rest of this experiment.
5. Turn off the flame and then very slowly and carefully add the weighed sodium chloride sample you prepared to the hot water. Restart the flame and stir the solution with a stirring rod to dissolve the sodium chloride while bringing the solution to a gentle boil. Determine the temperature of the boiling salt water mixture. Record the value after making any adjustments based on error noted when measuring the temperature of the boiling water prior to adding the solute.
6. Repeat the boiling point determination for sucrose and calcium chloride, using fresh 100mL portions of water for each sample. There is no need to boil the water prior to adding the solute since you already know the thermometer's error. As a matter of fact, it is much safer to add the solute to the room temperature distilled water and then heat the solution to boiling.
7. Determine the temperature of the boiling solutions. Record the values after making any adjustments based on error noted when measuring the temperature of the boiling water prior to adding the sodium chloride in the previous step.

Data Table: Aqueous Solutions

FP	Particles / Compound	Mass Solute	Measured (°C) lab	Calculated (°C) formula	Error = (°C) difference
C ₁₂ H ₂₂ O ₁₁	1mol/1mol doesn't ionize	34.2g			
NaCl	<u>2 moles ions</u> 1 mole comp	5.84g			
CaCl ₂	<u>3 mole ions</u> 1 mole comp	11.0g			
BP					
C ₁₂ H ₂₂ O ₁₁	1mol/1mol doesn't ionize	34.2g			
NaCl	<u>2 moles ions</u> 1 mole comp	5.84g			
CaCl ₂	<u>3 moles ions</u> 1 mole comp	11.0g			

Calculations: Molality = m = moles of solute particles / kg of solvent

$$\Delta T_f = K_f m$$

$$K_f = -1.86^\circ\text{C/molal}$$

$$\text{FP} = 0^\circ\text{C} + \Delta T_f$$

$$\Delta T_b = K_b m$$

$$K_b = 0.52^\circ\text{C/molal}$$

$$\text{BP} = 100^\circ\text{C} + \Delta T_b$$

1. Convert the mass of each solute into moles.
2. Calculate the number of moles of particles (ions) for each solute using particles/compound in the above table.
3. Calculate the molality for each of the three solutions assuming that each solute was dissolved in 100ml of water. (Note: The density of water is 1.00g/ml.)
4. Calculate the change in temperature for the freezing point each solution and add it to the freezing point of water. Record this value in the data table.
5. Calculate the change in temperature for the boiling point each solution and add it to the boiling point of water. Record this value in the data table.
6. Calculate the difference between your measured value from your lab and the calculated value determined using the formula. Record the absolute value from this calculation in the data table.

Conclusion:

1. Which solute produced the largest depression in the freezing point? Which solute produced the largest elevation in the boiling point?
2. Which solute produced the smallest depression in the freezing point? Which solute produced the smallest elevation in the boiling point?
3. Are the measured temperatures for the solutions consistent with the trend you would expect based on the number of particles produced when each of the respective solutes dissolve? EXPLAIN.
4. Explain the differences between the measured temperatures and the calculated temperatures (i.e. list three possible sources of error).
5. Describe, on a microscopic basis, how a liquid boils and how the addition of the solute changes this process.
6. A solution is made consisting of 2.05g aluminum chloride (AlCl₃) dissolved in 9.87g of water (H₂O). Calculate the freezing point and the boiling point of this solution.

Appendix E

Properties of Solvents in Solution Lab

In studying solutions, we have studied the effects of temperature and amounts and how they affect solubility. We have calculated the concentrations of solutions, and looked at reactions that occur in solutions and their stoichiometry. Now we will see how becoming a solution affects the solvent. There are actually some very practical effects from solutions that are used in everyday life. Your research should include all of the following:

1. Record all research and observations in your lab journal.
2. Choose a property of solutions and a solute to study how it affects that property. You could choose one of the ionic compounds we have studied or choose another solute with approval.
3. Identify your variables and determine how best to measure them. Make a hypothesis about the relationship between your chosen variables. Identify an experimental control, and identify and monitor any control variables.
4. Identify the materials needed, noting any safety concerns, and develop the procedure needed to conduct a safe scientific investigation of your chosen property. Submit your procedure for approval before starting your investigation.
5. Analyze your data to determine if there is a relationship between your variables or not. Draw conclusions about the properties of solutions and provide an explanation for the evidence you have collected.
6. Discuss your results and explanations with other lab groups. Research properties of solutions and make connections to your results and explanations.
7. Present your conclusions and explanations to the class in a format you feel comfortable.

Your research might not occur in this order. You may skip steps, to return to them later, or you may find yourself doing a step several times to refine your process, or to further verify your results. Be sure to ask before changing any part of your procedure.