

THE EFFECTS OF PROJECT-BASED SCIENCE ON STUDENTS'  
ATTITUDES AND UNDERSTANDING OF HIGH SCHOOL CHEMISTRY

Thesis

by

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## **CHAPTER 1**

### **Introduction**

The following study investigated the effects produced by project-based science (PBS) on high school students' attitudes towards chemistry and conceptual understandings of phase changes and solutions chemistry. The study used student interviews and attitude surveys to determine any changes brought on by the involvement in a PBS curriculum. Results of this study may be used to validate the use of PBS instruction for high school chemistry classes.

### **Background**

PBS is founded upon constructivist principles. Piaget (1964) posed that children organize information in mental networks called schemes. They learn by altering previous schemes (accommodation) or adding to schemes (assimilation). Learning occurs when children become discontent with their previously held ideas and are forced to assimilate or accommodate new information. In this way children construct knowledge. The focus of PBS on real world problems promotes the metacognitive processes by which schemas are altered. By conducting inquiry investigations in PBS, students build upon prior knowledge and construct an internalized understanding.

Vygotsky (1934, 1962 translation) posited that children construct knowledge through social interactions with peers and adults. He contended that language is central to both knowledge construction and thought. In other words, Schemas are based in language and modified through discourse. Project-based science also promotes learning through

the social learning theory proposed by Vygotsky (1934, 1962), which ties the spoken word to a network of mental thoughts. Vygotsky distinguished between internal and external discourse, which is the difference between thinking and discussing ideas with others. According to Vygotsky, learning is situated in the community and children use cultural tools to aid in discovery. By working in collaborative groups, PBS students engage in a verbal exchange of ideas that allows them to form understandings by putting their thoughts into words. Being able to verbalize thoughts requires a complete understanding of the material and exchanging ideas allows students to develop a comprehensive understanding. Additionally, the verbal exchange of ideas allows students access to various viewpoints and opinions.

The idea for PBS has roots in the Progressive Movement, which emphasized the importance of experience in learning. Progressivists such as John Dewey (1938) advocated the use of group work on investigative projects and learning by doing instead of rote memorization. Groups are motivated through a shared purpose in completing a project, which motivates them to devise a specific plan to meet the requirements of their goal. In addition, the Progressive Movement emphasized the importance of tying in the community to learning, which helps the students feel a connection with the material.

Project-based science presents an instructional method that allows teachers to engage their students in deep investigations of course material while solving a problem of some intrinsic value to the students. By investigating a problem, students are able to experience the content through their own interpretation rather than relying on the teacher to deliver information. A PBS unit starts with a driving question, which directs student-

designed investigations and ultimately leads to the production of an artifact, which displays the students' understanding of the concepts (Krajcik, Czerniak, & Berger, 1999). This allows students to internalize the information through the Constructivist approach to learning. By working in cooperative groups, students are also able to socially construct an understanding and verbalize their thoughts.

### **Positionality**

This study aims to determine the effect of PBS on high school students' understanding of chemistry and attitudes toward chemistry. Prior to entering the classroom as a teacher, I worked a graduate research assistant conducting research in PBS, which sparked my initial interest in the pedagogy. As an in-service teacher, the motivation of future students and their academic performance is a major concern to me. Instructional methods that address these issues are valuable to both current and future teachers.

### **Rationale**

With respect to the discipline of chemistry, students often experience instructional approaches that leave them with a lack of understanding and a negative attitude towards chemistry (Alrehaly, 2011). In my experience as an undergraduate chemistry major, I found that many of my peers in other departments expressed a negative attitude toward chemistry and many thought I was crazy for my choice of study. Often times, my peers recalled their chemistry education as being "too hard" or "uninteresting". It is this consensus towards chemistry that motivated this study.

Many students fail to make connections between the content and everyday life. When this failure combines with academically challenging work, students can develop adverse feelings towards the subject of chemistry. Negative attitudes towards chemistry lead to low enrollment in chemistry majors and pursuit of careers in chemistry related fields, a current trend in the US (Alrehaly, 2011; Robinson & Ochs, 2008). In addition, many students leave chemistry classrooms with an incomplete or incorrect understanding of chemical phenomena (Nakhel, 1994). This leads to a public that lacks scientific understanding and literacy. The idea that chemistry can explain everything we encounter in our daily lives at the most basic of levels (particulate) is what initially motivates many chemists. When students are not given examples of chemistry that relate to the real world, they fail to see the wide applicability of its' content. Project-based science allows students to experience the use of chemistry content in a real world scenario while forming a comprehensive understanding of the material. Through my own previous observations of this campus as a research assistant, I have seen PBS students in a chemistry class actively involved and committed to a project goal. This is in contradiction with the level of engagement usually seen in a traditional, lecture-based lesson. The approach to chemistry instruction at the PBS-based campus helps to make the material more exciting for students, which in turn engages them in the investigation.

### **Theoretical Framework**

The qualitative aspects of this study are rooted in several theoretical perspectives. Through the interviews, the students' thought-processes in solving content-related

problems were examined. This allowed for determination of comprehension on the application level and not just an algorithmic solution (i.e. numerical value). This portion of the study is derived from the constructivist perspective, which seeks to find how participants construct their knowledge or experience under the given conditions. Themes of how knowledge was constructed and stored were examined through these interviews. Since PBS students experience the content through investigation rather than delivery by the teacher, the construction of knowledge is internalized. As a result, PBS students may approach questions in a different way than traditionally instructed students. More specifically, PBS students may form a deep understanding of the content that allows them to think in-depth about a problem.

A phenomenological approach was also appropriate here, as the goal was to investigate common trends of students' experiences in a PBS atmosphere (Moustakas, 1994). Moustakas (1994) points out that knowledge of an object is derived from experiences and so phenomenological knowledge seeks to understand the relationship between experience and the phenomenon. The phenomenon being investigated in this study was student understanding of chemistry content. This will be examined by looking at common themes of experiences associated with PBS units. This understanding was focused on specific units of study to help refine the scope.

Additionally, as mentioned above, I have personally witnessed students at the PBS campus actively engaged in their project and working collaboratively towards the end goal. This active involvement may lead to a more internalized understanding of the concept and a more scientific approach to problem solving. Also, research shows that

students in a PBS environment exhibit gains in academic performance and concept understanding (Kanter & Konstantopoulos, 2010; Rivet & Krajcik, 2004; Schwartz, et al., 1998).

Determining students' thought processes was difficult for a number of reasons. In order to avoid guiding students to desired responses, the research avoided leading questions and used probing questions to get students to express their thoughts while solving the problem. Additionally, my differing roles for each population year may have lead to a data collector bias. For this reason, identical protocols were used for both populations and neither confirmation nor corrections were given during the interview. Also, as mentioned above, questions during interviews were limited to those designed to elicit the student's thought process. This helped to prevent preferential treatment of subjects in either population, by leading students to the correct answer.

It is the hope of this researcher, that this study will help illuminate benefits and limitations of PBS so that it can be more effectively implemented in chemistry classrooms



## **CHAPTER 2**

### **Literature Review**

The research for this study focused on three areas: project-based science, attitudes towards science, and student understanding of chemistry concepts, specifically phase changes and solutions chemistry. For this study, project-based science (PBS) will be defined as an instructional method that uses authentic questions to engage students in long-term, collaborative investigations that results in the production of an artifact (Dickinson & Jackson, 2008). Attitudes investigations will focus on student attitudes towards science, chemistry, and learning chemistry.

#### **Importance of Science Attitudes**

Current trends in American higher education show a decreased enrollment of students in majors related to science, mathematics, and engineering. This is exceptionally troubling because, as the president of the National Science Teacher Association (NSTA) accurately predicted, by the year 2014, 15 of the 20 fastest growing occupations will require a background in science or mathematics to ensure job success (Froschauer, 2006). Additionally, in 2006 the US ranked 32<sup>nd</sup> out of 90 countries in production rate of undergraduate science degrees. For example South Korea, a country with a population that is one sixth of that of the US, graduates as many engineers each year as US universities (Froschauer, 2006). Research has shown that students who enroll in only the minimum requirements of science and mathematics claim it is due to “lack of interest, the

difficulty of science, and the perception that it [is] not needed for the future” (Robinson & Ochs, 2008, p. 345). Students’ perceptions of the discipline of science influence their enrollment and involvement in science courses. It is this attitude toward science that makes students avoid science majors. Mager (1984) points out that if a student experiences aversive conditions when being taught a subject, they will develop and express avoidance responses to that subject. He asserts that the conditions and consequences students encounter when learning help develop their attitude toward that subject.

**Attitudes Toward Science.** Martin Fishbein (1963) purposed a model to describe the relationship between a person’s beliefs about an object and that person’s attitude toward that object. According to Fishbein, an attitude is defined as “the evaluative dimension of a concept”, and is a function of a person’s beliefs by the algebraic equation:

$$\sum_{i=0}^n a_i b_i$$

where  $B_i$  is the belief ‘i’ about the object,  $a_i$  is the evaluative aspect of  $B_i$ , and  $N$  is the number of beliefs (Fishbein, 1963, p. 233).

A person’s beliefs about an object are a result of past experiences with that object and the beliefs of those who the person is close to. It follows then, that according to Fishbein’s theory, a person’s attitude about an object results from their prior experience with the object as well as the influence of those close to the person (such as parents and teachers). Mager (1984) supports the former assertion by claiming that a positive attitude toward learning a subject will result from conditions and consequences present at the

time of learning, which the student considers to be favorable; on the other hand, a negative attitude toward learning will result from exposure to aversive conditions and negative consequences. He refers to these positive and negative attitudes by the actions they evoke, that is, either approach or avoidance. Mager goes on to discuss the importance of modeling for students to develop a positive attitude toward learning. Here, the influence of the teachers and parents comes into play. Children learn from observing their parents and begin to reflect the attitudes and behaviors of their parents. Additionally, the environment and conditions present in a teacher's classroom influence a student's future attitudes towards certain subjects and activities. For this reason, it is important to find an instructional method that promotes positive associations with the fields and study of science to ensure students do not avoid these subjects.

In one study, Alrehaly (2011) found that participants who avoided science courses attribute their lack of interest to a negative experience with science or science teachers, their parent's attitude toward learning, or socioeconomic status. Alternatively, those who had a positive memory of their science education and whose parents expressed a positive, supportive attitude towards learning, maintained an interest in science that was transferred to their children. The author concluded that "participants interest or non-interest in science was influenced by science teachers and parents attitudes" (Alrehaly, 2011, p. 46). By allowing students to guide their own investigations based off of their interests and the interest of the peers, project-based science could help teachers reinforce positive memories of experiencing science content by making the content more intrinsically valuable to students.

Science attitude has been the subject of numerous recent studies. Bennet & Hogarth (2009) found that there was a sharp drop in positive attitudes toward science among students between the ages of 11 and 14. The research revealed increased responses concerning the difficulty of science lessons in students of this age. Providing meaningful context through PBS units could help students persevere through content struggles in order to accomplish an end goal and prevent this negative feeling. Ravad & Assaraf (2011) found the most significant factors contributing to tenth-grade students' attitudes towards science were interactions with the teacher, the relevance of the topics, and the variety of teaching methods used during instruction. Ornstein (2006) found that students who participated in more hands-on and inquiry-based lab experiments showed an increased positive attitude towards science. Baseya and Francis (2011) compared the effects on student attitudes of two types of inquiry labs: guided inquiry labs and problem-based labs. Their results showed that students' attitudes towards labs were more dependent on aspects of the lab such as excitement and connection with class material than on the type of lab activity. Difficulty of the lab showed a better relationship of positive attitudes with guided-inquiry than with problem-based activities, which highlights the importance of increasing scaffolding for students as problems become more difficult. These studies suggest that student involvement in an instructional method, such as project-based science, that emphasizes inquiry-based and hands-on investigations could cause students attitudes towards science to improve. Sadi and Cakiroglu (2011) found no significant difference in student attitudes towards science between hands-on laboratories and didactic instruction. The authors acknowledge that many factors outside

of the control of the study can influence student attitudes such as home life, interaction with teacher and peers, media messages and personal experiences of students.

All of these factors can be addressed through project-based science. Since each collaborative group is conducting unique investigations, teachers must spend personal time with each group in helping to guide and facilitate student learning (Polman, 2000). Topics that are relevant to the students in order to motivate investigation is a primary component of a PBS unit, and as these investigations are designed based on students' interests, the activities are chosen by the students as needed for their purposes.

**Measuring Science Attitudes.** Many publications have presented instruments for measuring science attitudes. In a recent literature review, Blalock et al. (2008) found that most instruments measure student attitudes in one or more of four categories: attitude toward science, scientific attitude, nature of science, and scientific career interests. The authors described attitude toward science as the emotions felt toward the subject of science, including interest and enjoyment. This category was defined to include attitude toward school science as well as science in general. Scientific attitude, as described by the authors, represents thinking and acting scientifically. Scientific attitude includes “respect for evidence, objectivity, open-mindedness, and questioning” (Blalock et al, 2008, p. 964). The nature of science is found to be the category with the biggest variance in definition among the literature reviewed. It can be described as encompassing the culture of the scientific community and includes scientific values, interactions, and practices. The final category involves measuring career aspirations. Blalock et al. (2008) reviewed 150 peer-reviewed articles that presented 66 different instruments for

measuring science attitudes. The researchers found that many instruments did not include fundamental psychometric components such as reliability and validity. Additionally, most instruments were presented in literature only one time and were normally developed for the use of a single study. This lack of repetition in use makes it difficult for the education community to discern the reliability of these instruments or to correlate findings from multiple studies. Indeed, many studies describe developing their own instrument because of needs of the study including different languages and goals for data (Bennett & Hogarth, 2009; Shah & Mahmood, 2011). It may be beneficial then to administer existing instruments in order to determine effectiveness in different scenarios. Therefore, instruments that focus on multiple of the categories identified above rather than a specific study should be identified and used. The instrument used for the present study (described in detail below) is one that was validated and found to be reliable by multiple measures, in order to address these concerns.

**CLASS-Chem.** For the purpose of this study, the area of interest is the students' attitudes towards science, or more specifically, their attitude toward chemistry and learning chemistry. Many instruments available have been designed to assess student's attitude toward the subject of science in general rather than a specific discipline within the field of science (Blalock et al., 2008). Researchers at the University of Colorado in Boulder have developed the Colorado Learning Attitudes towards Science Survey (CLASS) to investigate student attitudes towards physics and learning physics (Adams et al., 2006). A detailed description of the administration, scoring, and logistics of the

survey is given in the next chapter, but a brief discussion of the survey development will be provided here as well.

The CLASS uses a 5-point Likert scale (strongly agree to strongly disagree) to answer questions related to learning in the subject field. Calculating the percentage of responses for which the participant agrees with the expert responses provides a score to be used for data. Originally developed for measuring attitudes in physics, the authors have since created modified versions for chemistry and biology.

This survey differs from other attitude surveys by the fact that categories of questions included on the survey were empirically determined from student responses. In the original version, emergent themes among responses from students correlated to general views about physics held by students. Other attitude surveys use *a priori* grouping, where groups of questions are established based on the developer's opinion of views held by students. By empirically determining question categories, the creators of this survey are able to highlight and address views that are consistent among students. Statistical analysis of student responses allows for coherence among responses to be determined and used to define categories of questions (Adams, et al, 2006). The authors of the CLASS survey also cite numerous features of this instrument that distinguish it from other attitude surveys (Adams et al, 2006). For one, the CLASS instruments are aimed at a wide scope of issues which experts agree are important to learning science, rather than being too content specific or going into great detail of certain themes. Also, the questions were carefully worded so that only a single interpretation is possible and readers of various levels are able to understand them. Scoring is made quick and easy

since the responses from both “expert” and “novice” participants are unambiguous. Additionally, the questionnaire was designed to allow for in-depth thought of each question within about ten minutes. The above listed features also make the survey very easy to administer and score. Finally, as previously stated, the categories of questions are backed by empirical data. This is beneficial for the present student, as the multiple categories can give a holistic view of student attitudes

When developing this survey, the creators administered numerous validity and reliability tests. The wording of the questions was subject to validation interviews with both experts in the given field and students to ensure that no questions could be interpreted in more than one-way. After revising from the interviews with experts on the wording of questions, the survey was given to numerous experts with experience in physics and teaching physics to determine and confirm the “expert” view for all questions. Student interviews consisted of going over student responses with the student and allowing them to explain any thoughts they had about the questions or if they did not answer, why they chose not to. These results showed that both experts and students had consistent interpretation of the questions. Those statements that were unclear or subject to multiple interpretations were either reworded or dropped. For determining the categories of questions, initial categories were defined by combining the categories outlined by experts with statistical data from student responses through the use of reduced basis factor analysis (Adams et al, 2006). This was repeated numerous times with removing statements that did not fit into any category and adding statements with a high correlation to the group. The authors also assert that it is important when interpreting results to



acknowledge the fact that other factors besides instruction will have an affect on student attitude such as student age, gender, level of study, or time off of school.

A major concern with this type of survey is if student responses are their true feelings or what they believe they should answer (Adams et al., 2006). To determine this, the creators of CLASS administered the questionnaire and asked students to respond to what they think and what a physicist would answer, for each question. The following semester the CLASS was administered in the traditional format and results were compared with the previous survey. From this it was found that typical student responses more closely reflect answers to the “What do *you* think?” question. The reliability was tested by comparison of responses in two different physics courses with large enrollment over the course of two semesters. In both classes, consistent responses were seen across both semesters with reliability ratings around 0.98 - 0.99 for all agree and disagree responses (Adams et al., 2006).

The successful application of the CLASS Physics survey and its’ high reliability and validity, inspired the development of the CLASS Chemistry survey (Barbera et al., 2008). This was developed in a similar manner to the physics survey described briefly above. The CLASS Chem survey differs from other chemistry attitude surveys, such as Chemistry Expectations Survey (Grove & Bretz, 2007) and Chemistry Self-Concept Inventory (Bauer, 2005), in a few important aspects. The Chemistry Expectations Survey (CHEMX) contains statements that refer to specific courses or fields within chemistry, while the CLASS Chem survey addresses the subject of chemistry as a whole (Barbera et al., 2008). Since all three of these surveys were developed at the collegiate level, it is

more appropriate when investigating the attitudes of high school students to use a survey that focuses on the subject of chemistry as a whole rather than specific fields, which may be too in-depth for use on the high school level. Also, as with the physics version of the CLASS, grouping of statements is backed with empirical evidence; while other surveys such as CHEMX use groups defined by the experts (Barbera et al., 2008). Additionally, the statements in CLASS Chem are carefully worded to prevent any misunderstandings or alternative interpretations.

The validation tests performed on the physics version (Adams et al., 2006) were repeated for the chemistry survey. Following student interviews, two questions from the physics version used in the chemistry version were reworded, three were dropped due to ambiguity, and 11 out of the 20 additional statements added that relate to chemistry were kept (Barbera et al., 2008). This ensures that the questions can be understood the same by all participants on the collegiate level.

The expert responses were determined by administering the survey to numerous chemistry faculty members at several universities. This also allowed for further feedback concerning the statements in the survey. The data from this gave consistent responses to 45 of 50 statements. Of the statements that the experts did not agree on, three concerned how students think they learn. These were excluded from scoring but included in the survey to provide additional information for test administrators. The concurrent validity of the survey was confirmed by administering the survey to populations that would be expected to have different attitudes (i.e. chemistry-majors and non-chemistry majors). The results showed differences between the groups in the percentage of statements they

agreed with the experts on. Data from students enrolled in different chemistry courses was used to test the reliability of the survey. The average Cronbach's  $\alpha$  value for the CLASS-Chem survey was found to be 0.89 (Barbera et al., 2008). Additionally, consistent correlation among responses from students enrolled in large chemistry courses over several semesters confirms the reliability of the survey (Barbera et al., 2008).

### **Student Understandings in Chemistry**

Chemistry, like all science subjects, contains three levels of knowledge: macroscopic, microscopic (or submicroscopic), and symbolic (Devetak, Vorinc, & Glazer 2009; Johnstone, 1991). The macroscopic level involves observable objects and events, along with their properties. The microscopic level describes the observed phenomenon on the particle or molecular level. The symbolic level utilizes numerical and symbolic representations to describe microscopic phenomena. This includes formulae and mathematical calculations. Numerous studies address the importance of students developing an understanding of the particle nature of matter in order to fully understand the field of chemistry (Abdo & Taber, 2009; Gabel et al., 1987; Hinton & Nakhleh, 1999; Nakhleh, 1992; Ozmen, 2013). Gabel, Samuel, and Hunn (1987) affirm that students' ability to represent chemical phenomena on the particulate level is important for the understanding of fundamental concepts such as changes in state of matter, stoichiometry, gas laws, and solution chemistry. Students learning the content through experience and investigation, and then having to decide how best to represent their understanding in a PBS environment may help them to connect these different levels of understanding.

However, Nakhelh (1992) points out that many students have difficulty learning concepts at the microscopic level because they are less familiar with this representation and fail to make connections with fundamental concepts. This stems from students failing to connect the symbolic representations with the microscopic concepts.

Misunderstandings or incorrect preconceptions at the microscopic level can lead to algorithmic solving of problems rather than conceptual application and the view that macroscopic properties extend to the microscopic level (Rappoport & Ashkenazi, 2008). PBS may help prevent this memorized, step-by-step approach to problem solving by helping students develop skills to connect microscopic understand with macroscopic processes.

When problem solving, students utilize knowledge on all three levels of understanding to find a solution (Heyworth, 1999; Rappoport & Ashkenazi, 2008). Heyworth asserts that there are two basic mental processes that occur when problem solving. The first involves the student forming a representation of the problem based off of their conceptual knowledge of the information given. Indeed, Abdo et al. (2009) assert that chemistry, like many science subjects, is taught using models to represent phenomena. The second mental process uses a particular strategy to find a procedure, which will guide the student from the initial state to the goal. Thus, students employ both conceptual and procedural knowledge when solving a problem. In this sense, PBS benefits over traditional, lecture-based instruction with predesigned experiments and activities, by involving students in a problem-solving process that inherently connects the content being learned with the experience of applying it in a real world context.

Numerous articles have confirmed that students often enter science classes with preconceptions, or misconceptions, concerning the material (Calik & Ayas, 2005; Carr, 1984; Devetak, 2009; Hand & Treagust, 1988; Nakhelh, 1992; Nakhelh, 1994; Rappoport & Ashkenazi, 2008). These preconceptions are formed based off prior experience with content either in school or personal lives. Many of these preconceptions are regarding the particle or microscopic level of chemistry (Nakhelh, 1992). West, Fensham, and Garrard (as cited in Nakhelh, 1994) assert that students construct their knowledge of chemistry through formal instruction, public knowledge available in various forms, prior knowledge of science, practical experiences, and informal sources such as parents or friends. The constructivist approach allows for these preconceptions to be addressed and altered or corrected through the learning process (Calik, 2008). This extends to PBS classrooms since students must develop knowledge in order to accomplish a goal. Through their investigations on content-related problems, prior knowledge is altered and built on.

For the purpose of this study, two chemistry topics were selected for investigation: phase change chemistry and solutions chemistry.

**Phase Changes.** Students understanding of changes in the phase of matter is built on an understanding of the nature of matter. Liu (2007) found students' conceptual understanding of matter grows from elementary to secondary school. This long-term development of understanding led Liu to encourage introduction of matter at an early grade. In their study of Swedish students Adbo and Taber (2009) found that students' perception of the arrangement and spacing of particles among the three phases of matter

was on target. However they identified misunderstandings concerning the movement of particles in the solid state and the impact of the addition of heat on the distance between molecules. Students expressed a view that particles in the solid state had little to no movement, ignoring the vibrational motion of particles. Additionally, the representation of the increasing distance between particles as heat is added to the system was found to be over-simplified and lacked an explanation of the mechanism for this increase. The authors contend that students must obtain a thorough understanding of the particle model before they can sufficiently appreciate concepts such as changes of state. This highlights the importance of building and developing an understanding on the microscopic level in order for students to be able to explain the content on a macroscopic level and represent it through the production of an artifact.

Jasien (2013) examined conceptual problems associated with the processes of freezing and boiling not related to the particle view of matter, but instead resulting from struggles with terminology, lack of experience, and energy concepts. The author found that many students exhibited misunderstandings of physical phenomena based on experience, specifically a lack of exposure to natural phenomena and misinterpretation of classroom demonstrations.

The results of this study further emphasize the importance of being able to connect the symbolic level with the microscopic level in order to explain macroscopic phenomena.

**Solutions Chemistry.** Heyworth (1999) found that experts and novices initially identify key words to help categorize the problem. Expert students tended to link the type

of problem with a procedure from their memory and then work step-wise to select and apply the appropriate formulae. Novice students, on the other hand, would first attempt to find a formula which leads directly to the solution and when this failed attempt to fit given information into any formula available. Conceptual knowledge in the experts was found to be accurate and incorporated the necessary formulas. Novice student's conceptual knowledge consisted of misunderstandings concerning the term "molarity" and the concept of a mole. This resulted in the generation and use of random/incorrect formulas. Novice students would also memorize formulas and answer algorithmically.

Devetak et al. (2009) used semi-structured interviews to determine the secondary students' submicroscopic-level understanding on aqueous solutions and the dissolving of ions and crystals. Students were asked to both draw and describe the particle level of solution with different concentrations. This distinction is important since it gives students various methods to represent their understanding, as they might do in a PBS investigation. Interviews revealed that students hold many misunderstandings regarding solutions and concentrations. Students misrepresented spatial arrangement of solute molecules by either congregating them all at the bottom of the container or arranging them in some set order. Some students also failed to associate volume with concentration. Additionally, it was found that students misrepresent a saturated solution by leaving out molecules of un-dissolved solute. Students also struggled with differentiating particles, i.e. ions and molecules, and with describing ionic interactions. As this study did not distinguish between different instructional methods, the present study will seek to gain insight into student understanding specifically for a PBS classroom and may be compared

to these broader results. Additionally, the authors recommend that chemistry teachers consistently integrate all three levels of understanding in instruction. This can be accomplished through project-based science since students investigate the causes of macroscopic observations, within a real world context, and represent the understandings that are gained as a result of this investigation.

Calik and Ayas (2005) performed a similar study with students in grades 7-10 to determine the cross-age understanding of the terms ‘solvent’, ‘solute’, and ‘solution’. The authors found that students often struggled with defining and correctly using these terms and those who were able to recall information used it algorithmically. In some cases, the student’s preconceptions even outweighed their knowledge on the subject. Many students held the view that a solvent plays an active role in a solution while a solute is more passive. PBS may provide students with a context to connect these terms with the application of their knowledge.

### **Project-Based Science**

Recently, calls for reforms in science education have stemmed from policies such as Goals 2000 and the resulting state and national standards, as well as the adoption of Common Core Standards and the Next Generation Science standards (NGS Lead States, 2015) by many states. These reform movements call for, among other things, increased understanding of scientific processes and improving scientific literacy (American Association for the Advancement of Science, 2009). Project-based science offers a possible instructional method for the achievement of these reform goals.



**Theoretical Basis for Project-based Science.** Rooted in the constructivist theory of learning, Project-Based Science (PBS) allows students to form their own interpretation of material through carefully designed inquiry activities. Constructivism is based on the theory of learning put forth by Piaget (1964), in which children store information in their memory in the form of mental schemes. When new information does not fit into an existing scheme (disequilibrium), it must either be altered (assimilation) or a new scheme is formed (accommodation); this process results in learning. Thus, the children construct their own understanding by processing new and previously known information. Wink (2006) points out how chemistry lends itself to pedagogical constructivism through connections with its content, process, and premise. Students in a constructivist environment develop understanding by creating new ideas to solve a problem from existing information (Brooks & Brooks, 2001). In PBS, students engage in projects that allow them to form new understanding of material by experiencing the content and solving a real world problem.

The idea of using projects in an educational setting is not a new one. Kirkpatrick (1918) argues for the use of purposeful projects in a social environment to allow students to engage in active, meaningful learning. The emphasis here is on the end purpose of the project keeping the student motivated and guided during the process. Kirkpatrick asserts, “The purpose is the inner urge that carries the boy on in the face of hindrance and difficulty... the progressive attaining of success with reference to subordinate aims brings satisfaction at the successive stages of completion” (Kirkpatrick, 1918, p. 325). Project-based science aims to intrinsically motivate students to solve a content-related problem in

a context that is authentic and relevant to them. This motivation will inspire students to take steps in order to achieve the end goal of the project.

It is through this process of successes that students are able to form connections and build knowledge that is applied to the goal of the project. This idea is expanded by the Progressive education movement, which ties learning with experiences. Dewey (1938) builds on this idea by affirming that a purpose generates a plan and method of action based on perceived outcomes and consequences of actions as determined by experience and investigation/observation. These purposes result from an initial desire, meaning the student's interest in the result and prior experiences are critical. For this reason, it is very important for PBS practitioners to find problems and contexts that are authentic and relevant to students' lives. Indeed, Dewey further discusses the dependence of learning scientific knowledge on students' acquaintance with its every day application. He points out that when learning material "in isolation", it can only be applied under the conditions of which it was learned (Dewey, 1938, p. 48). By students driving their own investigations, each collaborative group will determine how best to apply the content, and as such will learn how the content can be utilized to solve different problems.

Dewey also stressed the importance of a social environment in which all involved are free to contribute and feel a responsibility to the end result. This brings to light the importance of the teacher as a facilitator in these environments rather than a sole source of information and instructions. Students should be allowed numerous opportunities to discuss and exchange ideas, rather than spending majority of their time listening to teacher-led lectures. The social requirement of learning is also presented by Vygotsky

(1962). His social constructivist theory brings to light the connection between language and thought. In this theory, the meaning of words is tied to a generalization or concept, which is inherently an act of thought. This meaning forms a link between spoken words and thought, which helps students to internalize information (Vygotsky, 1962). The theory of social constructivism then, holds that students develop understanding of ideas by interacting with and interpreting information, in a social setting. From this, Vygotsky concluded that children learn best in social contexts. Vygotsky also acknowledged that children's experiential knowledge is a product of culture and environment and must be built on to gain deeper understanding. The culture of a group of students will influence how they build upon prior knowledge by using common cognitive processes that are developed through interactions with their environment. Students construct understanding by building on their prior knowledge and engaging in a social environment with the cognitive tools passed on through cultural development. Kukla (2000) expands on this by stating that constructivism developed out of the two schools of thought: sociology of knowledge and sociology of science. The former refers to the idea that facts and beliefs are socially constructed and the latter refers to the social aspect of the scientific community. The social construction of beliefs is not hard to imagine, as different cultures hold different values and opinions and thus will form unique views and beliefs. This is important to consider in a PBS unit, as the culture of the students can influence their decision-making during an investigation. Additionally, facts can be socially constructed through the social network in the scientific community. The exchange of scientific ideas

through communication with ones peers ties back to Vygotsky's social constructivism and is vital to PBS.

**Characteristics of project-based science.** PBS offers a method of instruction that allows students to engage in cooperative activities designed to provide them with opportunities to construct understanding of material through a meaningful application. Dickinson and Jackson (2008) define PBS as “an instructional method using complex, authentic, questions to engage students in long-term, in-depth collaborative learning, resulting in a carefully designed product or artifact”. Experts assert that a true PBS application consists of five features: (1) use of projects organized around *driving questions* that connect classroom content with real world problems the students find meaningful, (2) *investigations* that involve students in the processes of designing and conducting research that emulates the work of scientists, (3) the production of *artifacts* that result from the student investigation and serve to provide a tool to develop an understanding as well as a representation of their understanding, (4) students working in *collaborative groups*, (5) the use of *technological tools* to enhance investigations and presentations (Krajcik, 2015; Marx, Blumenfeld, Krajcik, & Soloway, 1997). A “project”, as used in this study, will refer to any unit of study in a PBS environment that is comprised of these features. Each of these features employs one or more of the theories that lead to the development of PBS and will be discussed in more detail below.

***Driving questions.*** The driving question in a PBS unit dictates what the students need to accomplish as well as the information that will be required. Since it is aimed at the end product, the driving question should involve a topic of interest to the students. By

choosing a topic relevant to student's lives, they can remain motivated and engaged throughout the course of the project. The desire to achieve the goal of a project will help students find value in intermediate steps that lead to the end result (Dewey, 1918). A good driving question should be feasible, worthwhile, contextualized, meaningful, and sustainable (Krajcik, Czerniak, & Berger, 1999). To be feasible, the question should be able to be answered by investigations designed and performed by students. A question's worth refers to the extent to which curricular content applies to the problem. A good driving question is contextualized when it is anchored to the students' lives and involves real world problems. To be meaningful means to be interesting to learners and sustainability is how well a question can sustain student's interest.

A driving question should be designed so that course material is applied to a topic that students find interesting or exciting. It should drive a student's investigation toward the desired goals of the project and require the student to develop knowledge through exploration of the topic. But a driving question does more than just guide the project. It helps students experience the science they learn in the classroom, in a real world scenario. A driving question should be broad enough to allow students to ask subsequent questions and design investigations in which they can collect and analyze information (Krajcik, 2015). This allows students to personalize their investigations and helps to internalize information more by building on prior knowledge.

***PBS investigations versus traditional investigations.*** Once a driving question has been defined, PBS gives students the opportunity to investigate the topic of concern. A distinction should be made between a true investigation and other educational science

activities (Krajcik et al., 1999). The general process in a teacher-led approach to scientific investigations, involves the teacher selecting the activity and providing students with step-by-step instructions, and having all students engage in the same activity. A less-restricted model may allow students to determine the steps they need to take in order to complete the activity. A true investigation involves generating questions to explore the topic, designing experiments, collecting data and materials, conducting experiments, and sharing findings with others in the community (Krajcik et al., 1999). Investigations allow students to make hypotheses and develop a complete understanding of material by collecting information and testing their hypotheses. This goes beyond a simple research project and requires students to decide what information they will need to complete the project and how best to present the information so their goal can be achieved.

Additionally, by asking their own questions and designing their own experiments, students are motivated and engaged with the activity. This active involvement allows for a better understanding of the reasoning for each step of the investigation and the connection with the content being explored. These investigations should take place over a period of time and within the context of the project, rather than short-term activities that are out of context (Krajcik, 2015). This ensures that investigations are integral to the process students go through during a PBS unit and are relevant to the problem being addressed, rather than isolated examples that are not connected with the context or artifact of the project.

***Production of Artifacts.*** The final result of any PBS unit is the production of an artifact, or end product, that represents the students' understanding of the material and

solution to the problem. Artifacts serve several purposes in the PBS unit (Krajcik et al., 1999). The production of an artifact is motivating for students because it can be a more enjoyable experience than taking a test or writing an essay. The artifact should represent the content within a misunderstandings context and as such is more engaging than a more traditional form of assessment. Marx et al. (1997) point out that because they represent student understandings, artifacts may also be used as a source of assessment. Also, by generating an artifact that represents their learning, students are forced to synthesize the information gathered in their investigation. This helps students form a complete understanding of the material by utilizing all knowledge, both prior and newly acquired. Since these products are concrete they can be shared with and reviewed by peers, which can enhance the social context of the project. The presentation of an end product requires students to verbalize what the content is that is being represented and how it was applied in order to accomplish the goal of the project. This gives students access to processes, techniques and content-knowledge that may not have been used in their own investigations, which helps further develop the students' understandings through social constructivism (Vygotsky, 1962)

***Student Collaboration.*** A key component of PBS is student work and involvement in collaborative groups. This feature of PBS evokes the social aspect of the social constructivist theory discussed previously. Student work is done in small groups where students can collaborate on ideas and debate different views or opinions. In collaborative group work, each member should contribute ideas and work with other members towards a common goal. Teachers can construct these groups so that students

interact with several different ability levels (Krajcik et al., 1999). Members should support each other so that each group member develops an understanding of the material. In addition to encountering other's views and prior knowledge, collaborative groups also engage students in a social, educational environment. This supports learning and comprehension through Vygotsky's claims that students learn in a social context where they are free to discuss and exchange ideas (Vygotsky, 1962).

It should be noted that in order to fully benefit from the group work, students must assume an active role in the group and feel a responsibility toward the end goal. Johnson, Johnson, and Roseth (2010) describe the benefits of group work by the social interdependence theory, which holds that positive interdependence among students yields interactions that can result in high achievement. A positive interdependence results from group members feeling that the goal is not met unless all members achieve the goal (Johnson, Johnson, & Smith, 2007). This will result in (1) increased substitutability, or how well one person's actions can be substituted for another person's actions, (2) inducibility, or being open to another person's influence and to influencing others, and (3) positive cathexis, which is investing positive psychological energy in something outside of one's self (Johnson et al., 2007). In this sense, the group work in PBS may be better labeled as "cooperative groups" as described by Cooper (2005). A cooperative group is one in which each member has a role that contributes to the overall goal of the group. Assigning roles in a group work ensures that all students are participating and are responsible for a portion of the group's work. This will in turn, help in motivation for students to contribute to the group goal, as they are personally accountable to their peers.



***Incorporation of Technology.*** The final feature listed by Marx et al. (1997) is the incorporation of technology tools to enhance investigations and artifact presentations. The use of technology can give students instant access to numerous sources for research via the Internet and give students several tools to help them construct meaning. Graphing and visualization tools can help synthesize and present information, while other technologies such as probes and thermometers can enhance student investigation and make them more authentic (Marx et al., 1997). Students can also collaborate with others via email and discussion boards. Krajcik et al. (1999) suggest that technology should be used as a tool to support scientific learning. However, not all experts on PBS consider technology incorporation to be a critical aspect of PBS (Dickinson & Jackson, 2008; Dickinson et al., 2010). While technology undoubtedly makes collection of research materials quicker, it is not necessarily required. Additionally, considering technology to be a key component of PBS may exclude some schools that lack technological resources.

***Challenges of PBS.*** Enacting authentic PBS presents several challenges for both students and teachers. As with any new instructional method, the departure from the traditional practice can present several challenges for teachers that need to be addressed. These challenges include meeting curricular standards, time restrictions, classroom management, teacher intervention and background, student assessment, technology integration, and transitioning from traditional instruction.

***Meeting Curricular Standards.*** For one, with the reliance on meeting state and federal standards in today's education system, teachers are required to cover a lot of material in a single school year. To help ease curricular tension, driving questions should

be designed so as to address several curricular standards and allow for in-depth exploration of each standard (Dickinson & Jackson, 2008). Dickinson et al. (2010) found that teachers using PBS find it easiest to align projects with curricular standards when they start with the standards and work backwards.

***Time Restrictions.*** The limited time offered to teachers in which to instruct students, presents an added difficulty to meeting these standards. This can make it difficult to meet time restrictions presented in the curriculum. Scott (1994) calls this the “trials and tribulations of time”(p. 82). She maintains that a 45-min period is too short for a traditional lesson to be effectively taught, much less an investigative laboratory experiment. This is especially true for PBS, since student investigations and discussions involve in-depth exploration and learning, that requires more time than broad coverage of the content and often will take longer than the teacher originally planned for (Marx et al., 1997). Krajcik, McNeil, and Resier (2007) point out that enacting project-based sciences presents a conflict between the in-depth coverage of content in PBS activities and the breadth of coverage outlined by state and federal standards. This is additional reason for designing projects by selecting a unit of several standards first, as multiple concepts can be covered over the course of the project (Dickinson & Jackson, 2008).

***Classroom Management.*** Another challenge teachers face is that of classroom management (Dickinson, Summers, & Jackson, 2010; Marx et al., 1997; Polman, 2000). The reliance of PBS on students working collaboratively to conduct research and produce artifacts, presents several opportunities for off-task behavior. Finding a balance between

an orderly classroom and the freedom for students to discuss ideas and investigate problems can be difficult.

In addition, as there are most likely several collaborative groups within a class, teachers can have difficulty dividing time among groups. Polman (2000) affirms that a teacher's work in a PBS classroom is comprised of a high number of interactions with several different student groups. Their day may consist of helping numerous groups on different projects simultaneously. Especially, if students are new to the investigative process, they will undoubtedly run into several speed bumps and will need assistance and guidance along the way. Observations by Polman (2000) indicate that a teacher's time is occupied with student-interaction more at the initial and finalizing stages of the project. But no matter what phase a project is in, teachers are required to maintain an active facilitator role in order to effectively aid the student learning.

***Teacher Intervention and Background.*** A fourth challenge that arises, which is related to classroom management, involves limiting teacher control of the student investigation process. As Dickinson et al. (2010) assert, the teacher in a PBS classroom must "provide adequate scaffolding for students to succeed without stifling student investigations" (Dickinson et al., 2010, p.2). Scaffolding will be defined as any instructional activities designed to support and enhance student investigations. As traditional, lecture-based instruction requires teachers to act as transmitters of information, when shifting away from this practice, teachers may be inclined to divulge too much information in response to student questions that would result in less investigation and subsequent knowledge construction. The difficulty here is to guide

students towards the curricular goal without delivering the information directly.

Successful scaffolding is often related to a teacher's content knowledge (Marx et al., 1997). This leads us to the next challenge: PBS requires teachers to possess extensive content and pedagogical knowledge (Kanter & Konstantopoulos, 2010). Mastery of the subject matter can help a teacher in designing effective driving questions and PBS units as well as aid student investigations (Blumenfeld et al., 1991). Additionally, Toolin (2004) concluded that teachers with a strong pedagogical and educator preparation background are more likely to successfully implement PBS.

***Student Assessment.*** Marx et al. (1997) also assert that assessment requirements in PBS are often difficult to design and may clash with traditional, ubiquitous approaches such as testing. Since student learning is manifested in the form of production of an artifact, determining how to measure student understanding and learning can be difficult and subjective. Also, as PBS students are exposed to classroom content through various methods and in varying degrees, traditional testing is often rendered inadequate.

Therefore, PBS units require teachers to rethink how students should be assessed and attempt to move away from tests. Roadblocks to this are often met from administration and community pressures based on traditional assessment views. One solution to this challenge may be performance-based assessment, where a student is given a task or problem and scored on their ability to complete or solve it (Colley, 2008). Rather than picking an answer from a list, students construct their own answer that reflects their learning. Since the skills and methods needed to complete either a structured- or an open-

ended assessment task relate to scientific process skills, Colley claims this form of assessment can lend itself to a project-based learning environment.

***Technology Integration.*** Another challenge, which may or may not arise, is the integration of technological resources (Marx et al., 1997). If teachers lack proficiency with technology, they may find it difficult to help students utilize the resources available. Additionally, many schools lack the technological resources to provide students with opportunities for further investigation and presentation methods.

***Transition from Traditional Instruction.*** A final challenge faced by both students and teachers is the transition from traditional, more structured and teacher-centered instructional methods, to a PBS environment. This dramatic change will require those who have been teaching for a number of years to alter the well-practiced methods they have developed and become comfortable with. Increased in-service training and staff meetings where fellow teachers discuss successful implementation of PBS may help these traditional teachers feel more comfortable and prepared when making the transition to PBS (Toolin, 2004). Additionally, teachers who were involved with pre-service training in PBS claimed this was critical for adoption in the classroom (Dickinson et al., 2010).

The transition from traditional educational practices to PBS methods can also be difficult for the students (Polman, 2000). As students are accustomed to traditional instruction classrooms, they tend to feel more comfortable in these environments (Ladewski, Krajcik, & Harvey, 1994). As shown by the example given by Polman (2000), students often have a misconstrued idea of what a project is. Students' experience

may lead them to question the need for producing an artifact or drawing original ideas from research. They may fear the lack of structure given to them, based on previous work, which required specific formats and gave lists of requirements for completion. The subject refers to this type of project as “standard library research”(Polman, 2000, 53). Furthermore, students may feel that previous projects lacked an ultimate “answer” and was more a collection and presentation of facts. This standard view of project-like work needs to be changed if students are to be actively engaged in the PBS process. It may be necessary to initial give some instruction on what a project is and what it means to complete a project in PBS. Students may also feel deterred by the increase in work and independence related with PBS investigations (Blumenfeld et al., 1994).

**Benefits of PBS.** Despite these challenges, many benefits have been seen from PBS use in science classrooms including academic performance, concept understanding, and attitudes.

***Academic Performance.*** Schneider, Krajcik, Marx, and Solloway (2002) showed that students participating in a PBS curriculum were not only prepared for national science achievement tests, but also outscored the national sample on the 1996 National Assessment of Educational Progress (NAEP) science exam. Schneider et al. administered the 12<sup>th</sup> grade test to a sample of 142 10<sup>th</sup> and 11<sup>th</sup> grade students enrolled in PBS courses and compared their scores with those of the national sample. They found that the PBS students’ scores were relatively homogenous across the sample population and that low- and high-scoring questions were similar between the sample group and the national population. As these national tests are based off educational standards, these findings

suggest that the PBS courses sufficiently covered the standards assessed on the exam. Additionally, the PBS students significantly outscored the national sample on 44% of the items included on the test. This may represent deeper understandings of the chemistry content for students enrolled in PBS courses compared to the national average. As the present study aims at determining the depth of understanding on chemistry concepts, these results suggest that the PBS students may express in-depth content knowledge.

Similarly, Rivet and Krajcik (2004) showed how PBS could promote learning of standard-related scientific content in urban schools. Working with twenty-four teachers in the Detroit Public School System, the researchers were able to help develop a PBS unit addressing balance of forces, simple and complex machines, and mechanical advantage. Using pre- and post-test assessments, the study found significant gains in achievement for the sample population of over 2500 students. Additionally, these gains were consistently seen as more teachers and students in the area subsequently participated in the PBS unit. This suggests that the results show more than a simple success of the PBS unit, but the potential for the method to be adopted in a variety of classrooms and adapted for various levels of achievement.

Karaçalli and Korur (2014) conducted a quasi-experimental study to analyze the effects of project-based science on students' academic achievement, attitude, and retention of knowledge in a fourth grade science class. The researchers used a pre-test, post-test design with a control group on a sample population of 143 students. Both achievement tests and attitude surveys were administered to the two groups before and after units of instruction. Results showed statistically significant effects in both

achievement and retention in the control and the experimental groups. However, students in the project-based group showed greater improvement in both of these areas. The authors concluded that students learn to construct their own learning and evaluate changes in their own behavior through application of the method. This will be targeted in the present study by looking at how students utilize knowledge to solve problems. The results of attitude surveys showed no significant change, but the authors attribute this to the short time frame study not being long enough to alter an attitude toward the method. As this study measured at the attitude of students towards PBS, the present study will examine how PBS influences students' attitudes toward the subject rather than the method of instruction.

Hansen and Gonzalez (2014) used longitudinal data from the North Carolina school system to investigate the effects of various classroom activities on academic achievement in math and science classrooms. The authors found that indicators for completing a project in science classrooms showed positive correlations with gains in achievement on the state eighth-grade science exam. However, this was not specific to environments that are entirely PBS-based nor was it constrained to specific definitions of a project. Instead, it relied on responses to student surveys in which participants identified involvement in an investigative project. Despite this limitation, the results suggest that involvement in science projects may help to develop a deeper content knowledge compared to other instructional methods.

***Concept Understanding.*** Schwartz, Vye, Moore, Petrosino, Zech, and Bransford (1998) used three different PBS activities to measure student learning in a sample of 5<sup>th</sup>



grade students. Results of data analysis on these activities showed increased student attention to real world constraints, significant increases in ability to answer standards-based content questions related to the learning goals of the projects for all achievement levels, and successful collaboration among group members to complete the steps of the project. These results indicate the ability of PBS to enhance student's understanding, application, and presentation of content material despite students' achievement level. This is especially critical as it highlights the connection between applying content to a real world problem and constructing a deep understanding of the content, as defined by educational standards.

PBS units were also shown to improve the academic achievement of minority students (Kanter & Konstantopoulos, 2010). Researchers developed a 10-12 week PBS curriculum for 8<sup>th</sup> grade science classes and gave it to nine different urban science teachers, along with professional development in content and PBS pedagogy. Student achievement was measured using a pre- and posttest administration of a test developed by the researchers to address the content of the curriculum at different levels of Bloom's taxonomy. Students' attitudes toward science were also measured using a pre- and posttest attitude survey covering five attitudes constructs that focused on value or relevance of science, interest in science, and efficacy related to science. Results indicate that a PBS curriculum produce an increase of science achievement. The overall gain found among students was greater than that of the average transition from one grade level to the next, when compared to the normal effect size gains of science achievement on a national test. The authors did find a significant decrease in student attitudes when

compared with level of teacher knowledge, however student survey data revealed that a higher frequency of inquiry activities correlated to several significant increases in student attitude. This suggests that frequent involvement in a PBS environment may positively increase students' perception of value in science, interest in science, and efficacy in using science knowledge. Additionally, these indicators were also found to increase minority students' plans to pursue science majors and careers in the future.

***Effect on Attitudes.*** Tseng, Chang, Lou, and Chen (2013) examined the effect of a project-based unit on students' attitudes towards science and engineering. A sample population of 30 college freshmen from Taiwan was used in this study. Data was collected in the form of questionnaires and semi-structured interviews designed to examine students' attitudes towards STEM before and after involvement in a PBS unit. Results showed significant increase in students' recognition of STEM's importance to science and engineering and their future careers. Many students acknowledged the importance of STEM to society and making the world a more efficient place. Increasing awareness of the connection between science content and future careers, along with the importance to society, may help motivate more students to pursue careers in science and engineering.

In another study, Berg, Bergendahl, and Lundberg (2003) compared the impacts of expository vs. inquiry labs on college chemistry students' attitudes. Students enrolled in an introductory chemistry course were given either an expository or an inquiry-based lab format. Prior to performing the lab, student attitudes toward learning science were measured using a questionnaire to determine those with low attitudes (negative) and those

with high attitudes (positive). The study found that students presented with an inquiry-based assignment that allowed them to ask their own questions and design their own investigations resulted in more positive outcomes than those that explicitly list steps of the assignment. Students participating in the inquiry labs were able to easily describe what they were doing in the experiment and why, whereas only half of the expository lab students were able to do so. In addition to the inquiry labs also resulting in higher order thinking, these students also expressed more positive and motivated attitudes towards learning. This was seen in the increased preparation time, lab time, and reflective questioning done by the inquiry groups. The increased attitude towards learning chemistry brought on by the inquiry-based activity could lead to less adverse feelings towards the subject by students. As PBS relies on inquiry investigations in order to construct knowledge required, the results of this study may extend to students in a PBS environment.

### **Problem Statement and Research Question**

The problem of this study is to identify the effects of project-based science on high school students' attitudes towards chemistry and understanding of chemistry concepts. Questions that guide this study will be:

1. How are student attitudes toward chemistry affected by involvement in PBS?

2. What conceptual and procedural knowledge of chemistry concepts, specifically solutions and phase change chemistry, do students in a PBS environment gain?

## CHAPTER 3

### Methodology

The purpose of this study was to examine what affects, if any, project-based science has in a high school chemistry classroom. Specifically, this study seeks to identify PBS students' understanding of chemistry concepts and changes in attitudes towards the field of chemistry.

This two-year study utilized a quantitative pre-test-post-test design for assessing changes in attitudes towards science learning (See Table 3.1). Additionally, some phenomenological aspects were included to compliment this quantitative analysis by using a purposive sampling post-test only interview for assessing students' skill in solving chemical problems and their conceptual understanding of the units taught as part of this research. The phenomenon being examined is the understanding of chemistry content, which will be examined through common experiences with PBS.

Table 3.1

*Study design for CLASS-Chem Survey*

	Pre-Test	Method	Post-test
Year 1	O	X	O

*Note.* O- administration of CLASS; X – administration of instructional method

The following hypotheses framed the investigation:

Hypothesis 1: The implementation of project-based science will increase student agreement with expert opinions on the CLASS-Chem survey, as it immerses students in authentic application of chemistry content.

Hypothesis 2: Project-based science will enable students to utilize an understanding on a molecular level to answer chemistry questions and solve chemistry problems.

### **Setting**

The site used for this study is a high school in an ethnically diverse rural school district in the Southwestern United States. According to the state's education department, for the 2012-2013 school year, the district had 8087 students enrolled, of which 79.35% were considered economically disadvantaged. The district student population was comprised of 26.2% African American, 68.6% Hispanic, 11.3% White, 2.9% Asian/Pacific Islander, and 0.30% Native American. The district has two high schools. The larger and older of the two is a comprehensive high school that largely utilizes teacher-centered instructional methods, which rely on structured activities design by the teacher or department and lecture-based instruction. The second, smaller campus, Taylor High School (pseudonym), utilizes project-based and problem-based instruction exclusively. Taylor High School was selected for this study because it has successfully implemented project-based science for over eight years.

Taylor High School uses an entirely project-based approach and utilizes technology resources for instruction and education. The building is designed with large windows that connect each classroom to the hallways and the walls are covered with student posters and projects. There is an emphasis on small class size, with classes of about 15-25 students. Posted at the entrance to the school are photos of graduating seniors along with their college plans and college acceptance information. Also located at the entrance is a large room filled with tables and chairs and surrounded by glass windows that classes may use for project presentations. The campus includes two buildings of classrooms, a gymnasium, a cafeteria, a robotics and engineering shop, and an outdoor area with benches where classes may be taught. The school utilizes a trimester system where students earn credit for a single course over two trimesters rather than two semesters. This leaves the third trimester open for additional courses such as science and engineering electives. Classes are generally 75 minutes long with a shortened schedule on Mondays; this shortened schedule is due to an hour and a half late start to accommodate teacher planning and professional development in PBS. Additionally, most teachers and administrators at the school have received formal training in project-based instruction. Most classes are structured with an interdisciplinary approach that incorporates two subjects and are co-taught by two teachers. For example, English and social studies courses are co-taught and science is often co-taught with mathematics or engineering. Class lengths do not change regardless of whether the course is integrated or not. However, chemistry was taught as a single unit for the first year of this study. In the second year of the study, chemistry was co-taught with Advanced Biotechnology, an

engineering course that is part of a two-year engineering sequence that all freshman and sophomores at Taylor were a part of.

Taylor High School serves 331 students in grades 9-12. The student population is diverse: 19.0% are African American, 44.4% Hispanic, 32.3% White, 6.5% Asian American, and 6.5% mixed race. Students fill out an application for enrollment at Taylor High School, though there are no admission criteria other than successful completion of the 8<sup>th</sup> grade and promotion to 9<sup>th</sup> grade. A lottery system is then used to select students who will attend school at the campus.

### **Participants**

Taylor High School employs teachers who have had experience and education in project-based science. The chemistry teacher at this campus during year one of data collection was Stacey (pseudonym), who has a BA in biological sciences and composite science 8-12 certification. At the time of data collection she had been teaching at this campus for five years, which is as long as the school had been open. Her teacher preparation included a specific course in project-based science at a large, public university. The teacher for the year two data collection was the author of this study, who has a BS in chemistry and chemistry 8-12 certification. He was in his second year of teaching at this campus at the time of this study and conducted his student teaching on the campus as well. In addition to this experience, he also conducted many observations as a graduate research assistant in a project-based setting, which gave insights and exposure to PBS before teaching. Many experts note that pre-service training is important for correct



implementation of PBS (Dickinson, Summers, & Jackson, 2010; Ladewski et al., 1994; Marx et al., 1997; Toolin, 2004).

Student participants were selected using a convenience sampling based on the return of a signed parent-consent and student assent form on or before the day of the post-test 1. The attitudes survey pre-test sample population consisted of 33 students of the 94 total students enrolled in Stacey's chemistry course. For post-test 2, a sample population of 16 was used due to attrition. This attrition is a threat to the internal validity of the study, as the loss of subjects may introduce a bias in the results if the participants who did not return for the post-test would have answered differently. However, attrition was mostly random and as such did not affect the overall representativeness of the sample. This attrition was most likely due to scheduling conflicts, as the second post-administration occurred during the end of a grading period and students were unable to attend because they had work to finish for other classes.

Additionally, purposive stratified sampling was used to identify a smaller subsample of eleven students from the larger convenience sample for the pre-test administration, to be interviewed to gauge their understanding of chemistry concepts. In year one, pre-test scores on the CLASS-Chem survey along with overall class grades were used to select a stratified sample of interview participants with varying attitudes towards and success in chemistry. The researcher also attempted to match the overall demographics of the school with the interview sample. This allowed for a representative sample population.

In year two, an additional group of interviews was conducted with a sample of four students enrolled in chemistry at the same campus. Upon completing preliminary analysis of the initial data collection, the researcher felt additional interview data would benefit in identifying student thinking. Purposeful stratified sampling was used to identify these five participants; because the second set of interviews were conducted two years following the initial set, the students of this sample were enrolled in the researcher's class and had not taken the CLASS-Chem assessment. Consequently, interview participants were identified using course grades only to gain a range of achievement level. Participants for the second administration of interviews were selected based on overall course grade and demographics, as no survey data were available. All interview participants were assigned pseudonyms and are listed along with course achievement, demographic information and overall percent favorable scores from the first post-test in Table 3.3. For this purpose, the Achievement Level was assigned due to average grade and academic performance in the chemistry class, as determined by the interview's experience with students and course grades.

Table 3.2

## Student Pseudonyms and Demographic Information

Student Pseudonym	Gender	Ethnicity	Chemistry Achievement Level	Overall Percent Favorable (CLASS-Chem results)
Student A	Male	Hispanic	High	N/A
Student B	Male	Hispanic	High	59.5%
Student C	Female	White	High	48.9%
Student D	Male	White	Medium	73.3%
Student E	Female	Hispanic	Medium	48.2%
Student F	Female	Asian	Low	64.4%
Student G	Female	African American	Medium	40.9%
Student H	Male	Hispanic	Low	38.6%
Student I	Female	Asian	High	66.7%
Student J	Female	Hispanic	Medium	42.4%
Student K	Male	African American	Low	24.4%
Student A2	Female	White	Low	N/A
Student B2	Male	Hispanic	Low	N/A
Student C2	Female	White	Medium	N/A
Student D2	Female	White	High	N/A

**Units of instruction**

Two units of study were selected for investigation of this study: phase changes and solutions chemistry. Units of instruction focused on the same standards in Year 1 and Year 2. The first unit examines the properties of matter on the atomic level for the three different phases (solid, liquid, and gas). The second unit is built around properties of solutions and the process of dissolving. These units were selected because of the focus on

understanding the phenomena on a molecular level in order to explain observations on the macroscopic level. The wording of the state standards for each of these units is summarized in Table 3.4 below. The year 1 phase change unit focused on concepts of kinetic energy, phases of matter, and melting point. The year 2 phase change unit focused on phases of matter and kinetic energy, with specific attention given to changes that occur on the molecular level during a phase change. The year 1 and 2 solutions units focused on concepts of polarity, solubility, and saturation.

All units of PBS, including those covering content examined through the structured interviews, followed a similar procedure. First students are given a launch event that establishes the goal and context of the project by providing a framework and driving question. Students next complete a brainstorming activity that is utilized in all projects across the campus, to generate a list of prior knowledge on the subject(s) being covered in the project and a list of anticipated knowledge they will need to gain in order to produce the end product, or artifact. Then students design research and investigations to solve the assigned problem with aid from resources and activities designed by the instructor. This may include informative notes, resources, or small-group instruction; documents for planning and organizing information relevant to the project goals; access to laboratory activities and equipment; and individualized guidance for each group, or group member, based off of specific needs. Throughout this process, students construct an artifact to represent their solution to a problem or task. This culminates in the public presentation of the group's product to their peers, family members, community members, and guests from various industries.

Table 3.3

Standards used for structured interviews

Phase Change Unit Standards	Solutions Unit Standards
<p>The student knows the characteristics of matter and can analyze the relationships between chemical and physical changes and properties. The student is expected to:</p> <ul style="list-style-type: none"> <li>compare solids, liquids, and gases in terms of compressibility, structure, shape, and volume;</li> </ul>	<p>The student understands and can apply the factors that influence the behavior of solutions. The student is expected to:</p> <ul style="list-style-type: none"> <li>describe the unique role of water in chemical and biological systems;</li> <li>develop and use general rules regarding solubility through investigations with aqueous solutions</li> </ul>

### Role of the Researcher

At the time of the administration of the attitudes survey and the first collection of interviews, I was a pre-service teacher and conducted the study from the dual role of researcher and student teacher of the PBS classroom. For the interviews collected in Year 2, I conducted the study from the dual role of research and teacher. This was advantageous because it allowed for an in-depth observation of the PBS instruction being implemented. As this write-up took place a year after data collection and observation notes were not collected, lesson plans and assignments from Stacey and the researcher served as a data source on the exposure students had to the material.

### Definition of Variables

The CLASS-Chem survey examines student's attitudes in several different subcategories (listed below). Students' overall attitudes towards the subject of chemistry and the study of chemistry were measured over the course of a semester to examine if any

changes occurred while enrolled in the PBS course. Additionally, patterns in the thought process when solving problems related to two different units of study were examined through the semi-structured interviews.

### **Instrumentation**

Quantitative data will be obtained from a student survey designed to measure attitudes chemistry described in the following section. Additionally, the qualitative aspects of the study relied on structured interviews to gain insight into student understanding of concepts and application of knowledge.

#### **Colorado Learning Attitudes about Science Survey – Chem (CLASS-Chem).**

The CLASS-Chem survey (Barbera, Adams, Weiman, & Perkins, 2008) includes 50 statements concerning students' attitudes about learning chemistry. Participants respond to each statement on a five-point Likert scale ranging from "Strongly Agree" to "Strongly Disagree". The survey statements are divided among nine subcategories: personal interest, real world connect, problem solving: general, problem solving: confidence, problem solving: sophistication, sense making/effort, conceptual connections, conceptual learning, and atomic-molecular perspective of chemistry.

**CLASS-Chem reliability and validity.** Validity of the CLASS-Chem attitudes survey was assessed through three criteria, as described by Barbera et al. (2008):

1. Interviews with students and faculty to ensure that the wording and the meaning of statements are clear to the population and that their responses match with the explanations.

2. Consistent responses by experts to provide face validity and establish the expert response.
3. The ability to distinguish between target groups with expected differences, namely science versus non-science majors.

The interviews conducted for validity were initially done with a population of 40 students for the CLASS-Phy survey. As a few questions were added to this questionnaire in order to create the CLASS-Chem survey, additional interviews were conducted with 10 students enrolled in a range of chemistry courses, from an introductory course for non-science majors to a junior level organic chemistry course. In the interviews, students first completed the survey on paper then the interviewer read through each statement and had the student identify their response and give an explanation for their choice. Of the 20 chemistry-related questions that were added, 11 questions were kept that were determined by the authors of the survey to be the most valid and informative.

To determine the expert opinion, the authors of the instrument administered the survey to faculty members of the university where the survey was developed. Following the expert survey administration, 45 of the 50 statements were found to have consistent expert responses. Four of the statements that did not have consistent faculty responses were kept to provide probes for how students think they learn and their beliefs about the nature of science; these statements were not included in the expert-novice score.

A concurrent validity test was used to examine if a difference could be measured in the responses between populations that would be expected to have different views, specifically chemistry majors and non-science majors. As expected, the chemistry

students showed more agreement with expert responses on the CLASS-Chem survey than the non-science major students that were surveyed.

In order to test the reliability of the survey, data from the 2006 validity administration from nine chemistry courses at two different universities was analyzed and the authors of the survey found an average Cronbach's  $\alpha$  value of 0.89, which falls into the "good" range for the internal consistency. This score is not so high to suggest redundancy in statements. Additionally, the responses from students enrolled in introductory chemistry courses of two subsequent school years were found to have a high correlation for all statements on the CLASS-Chem survey. It should be noted that this reliability testing was done for college students only.

*Validation of the CLASS-Chem survey for high school use.* Because the validity and reliability of the CLASS-Chem survey were initially determined using university students, the researcher assessed the reliability and reading level of the test to ensure it was appropriate for high school students. The researcher assumed the chemistry content is valid at a high school level because high school chemistry content mirrors that of an introductory college chemistry course. To determine internal reliability a pilot test of the survey was administered within the first three weeks of the spring term. A sample population of nine 12<sup>th</sup> graders, not enrolled in a chemistry class, was used for the pilot test to determine the survey's applicability for high school students. A split half reliability test was used with these results. The responses on this pilot test were divided into even odd and a correlation coefficient was found to be 0.71588 after adjusting with the Spearman-Brown formula:  $\text{Coefficient} = 2r/1+r$ . This high correlation coefficient for such



a small sample size is critical as it shows the applicability of this survey to non-collegiate students, though it should be noted that this population is two years older than the sample population used in the study.

To ensure that the reading level of the CLASS-Chem items was accessible to high school students, readability was assessed using three methods. Readability tests of the CLASS-Chem statements scored a Flesch-Kincaid reading level value of 6.2, and a SMOG Index of 7. The Flesch-Kincaid reading score correlates to the grade level in the U.S. education system. The SMOG grade represents the number of years in education a student would need to understand the reading. The low reading level of the survey indicates that high school students should be able to comprehend the text with little to no difficulty.

**Chemistry problem sets.** Problem sets for the semi-structured interview were developed in cooperation with a faculty member in the chemistry department at the researcher's university. The researcher first provided the state educational standards (see Table 3.3) for the units of interest to the faculty member in order to establish face validity. Following this, both the researcher and the faculty member assisting with the development, generated several open-response style questions covering the two units. The faculty member and the student then met to discuss the application of each question and narrowed the questions down so that a variety of response types (i.e. written and drawing) were used to identify various levels of understanding (recall, application, and explanation).

Problem sets were designed to examine students' conceptual and procedural knowledge of the specific unit. Conceptual knowledge, as used in this study, was comprised of content related to the topic of study. The concepts used for problems were aligned with state and national standards (see Table 3.4). Procedural knowledge involved the problem-solving skills utilized and the approach used for each problem, including steps to finding a solution.

Problem sets (Figure 3.1) consisted of several types of questions. Simple definition and content questions were used to determine conceptual understanding. Students were also asked to draw microscopic representations to elicit further explanation of their conceptual understanding. These problems instructed students to depict what they would see if looking at the solution on the microscopic level.

The think-aloud protocol problem set consisted of five problems related to the specific units, which the students worked through on their own. The problem set contained both conceptual and procedural problems, which included drawings and description of specific phenomena related to the content. These problem sets were designed in cooperation with the teacher to ensure the problems assessed material covered during the unit of study. The final problems selected for the interview protocol are given in Figure 3.1 below. An outside expert with a Ph.D. in chemical education helped review the protocols in order to validate them.

**Structured interview protocol.** Interviews were conducted during student lunches so as not to interfere with class time. Interviews were done one on one in the chemistry classroom and were recorded using small audio recorders or laptop computers.

The author of the study and the faculty advisor conducted interviews. Interviewers were careful to stress that there was no right or wrong response, the purpose was to gauge insight into understanding and thought process. During the interviews, probing questions were used in order to get participants to verbalize their decisions and thought process when answering questions. Additionally, when explanations given in the interviews were brief, questions were geared to elicit memories of participants that aided in formulating a response. Special care was taken to ensure that questions would not guide the student's thinking or help them answer the question.

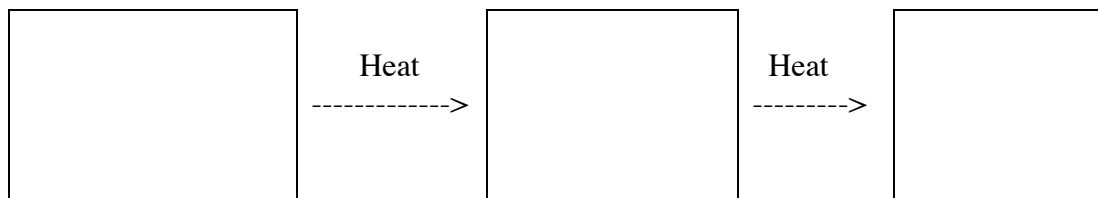
Figure 3.1. Problem sets from student interviews

How well do you feel you know chemistry on a scale of 1-5 with 1 being I know very little chemistry and 5 being I really understand chemistry?				
1	2	3	4	5
How well do you feel you understand the concept of polarity on a scale of 1-5?				
1	2	3	4	5
How well do you feel you understand the concept of phase changes on a scale of 1-5?				
1	2	3	4	5
1. Draw a picture of water molecules showing polarity. Explain the diagram as you draw it.				
2. Explain how the properties of water result in each of the following phenomena. You may use words or drawings				
Cohesion				
Adhesion				
Surface Tension				
3. In your own words, explain how salt dissolves when placed in water. Explain which is the solvent and which is the solute.				

Figure 3.1. Problem sets from student interviews (continued)

4. Describe the cause of polarity within a molecule in your own words:

5. Draw water molecules in a microscopic view for each phase



Why are some molecules a gas at room temperature and others a solid or a liquid?

## Procedures

As two different school years were used for data collection, each year will be described in the following sections.

**Year 1.** Two instructional units were selected for the interview portion of this study: (a) Phase Changes and (b) Solutions Chemistry. These units were chosen because both require an understanding of chemistry at the molecular level. The standards for both units are given above in Table 3.3.

For both groups of the interview population (year 1 and year 2) the units of study were taught using PBS units. In these units, students worked in groups of 3-5 to answer driving questions built around state standards. Each project culminated in a formal presentation of the group's artifact to their peers and outside panelists such as teachers and parents.

Year 1 students were exposed to the concept of phase changes during the first unit of study of the school year. This project focused on chemistry that is present in preparation of students' favorite recipes. The driving question used to direct student investigations in this project was "What chemistry can we uncover behind our favorite recipes?" The unit covered the following topics: (a) physical vs. chemical changes, (b) mixtures vs. pure substances, and (c) phase changes. Teachers provided small group instruction workshops on key topics. Students completed note outlines in an interactive notebook. As part of the final product, students were tasked with identifying the different phases of matter as they occurred during the food preparation process and discussing the molecular level phenomenon that produced the properties of each phase. The second unit in year one was a project that focused on rules of solubility, rates of dissolution, and concentration. Students were tasked with developing a recipe and brewing method to improve profits through a cost analysis for a large sweet tea producer while addressing the following driving question: "How can we use factors affecting solubility as we prepare a Cost Analysis Report for preparing our own version of a *Sweet Leaf*<sup>TM</sup> tea?". Students participated in small group instruction workshops and laboratory activities to investigate how temperature, nature of the solid solute, and agitation can influence solubility. As part of the final presentation, groups were tasked with creating a proposal complete with solubility data for their final drink mix and a saturation curve for ingredients such as sugar.

**Year 2.** The year 2 chemistry course was a cross-curricular class that integrated chemistry with advanced biotechnology. Students enrolled in this course also learned

about phase changes involved in food preparation as part of a unit focusing on matter. Just as in Year 1, this project started off the school year as an introduction to matter. However, this project focused specifically on the production of cheese and the physical and chemical changes produced by bacteria cells in order to highlight the use of a biological process. The driving question for this project was “What role does bacteria play in the production of cheese?” The topic of phase changes was specifically targeted in notes taken from a teacher-lead small group workshop as well as a skit designed to get students to act out the activity of particles in each of the three phases of matter. Students also observed the cheese-making process in order to identify when phase changes occurred. As part of the final presentation, students were required to explain the changes that occurred on the molecular level as liquid ingredients were heated and then turned into a solid.

Solutions chemistry was taught using two different projects that were taught back to back: one in which groups were tasked with developing a sports drink and another centered on Olympic doping controversies that were being discussed in the media at the time of implementation. In the first project students were challenged to use factors that influence the rate of dissolution to advise major sports drink companies on how to make the brewing process more efficient through the following driving question: “How can we use the factors that affect rates of dissolution to advise a corporation like Gatorade to help make the brewing process as efficient as possible?” In the second project, students were tasked with designing prototypes of probes that utilize solubility rules to quickly test blood samples of athletes to determine concentrations of target substances. The driving

question of this project was “How can we use the factors of solubility to design a prototype for a probe to quickly test for doping in Olympic athletes?” In both projects, students watched videos and participated in small group instruction workshops to develop an understanding of solubility and saturation. They also completed lab activities designed to explore solubility rules and rates of dissolution. As part of the final product for the sports drink project, students were required to justify their recommendations for brewing temperature, type and amount of agitation, as well as nature of solute based on the molecular phenomena produced by each. The final product for the Olympic doping probe required students to be able to describe and calculate concentration of solutions and to describe how substances dissolve. Additionally, students were taught units on chemical bonding that examined polarity and movement of electrons.

**CLASS-Chem and Interview Administration.** Attitude surveys and interviews were administered during lunch periods and students who participated were offered a pizza lunch for their cooperation. The pizza served as replacement for the lunch the students were missing in order to participate in the study. Students who chose not to participate were still offered pizza to make-up for the lunch that was missed. These lunch periods were arranged in coordination with teachers to ensure students did not have tests or major assignments/presentations due on the days of data collection.

**CLASS-Chem Survey.** The pre-test was administered within the first six weeks of the spring term. The post-test was administered within the last four weeks of the school year, at an arranged time that did not conflict with preparation or administration of the

end-of-year standardized tests. The Sweat Leaf Tea solubility unit fell between the pre- and post-tests so the CLASS measured changes in student attitudes as a result of this unit.

Scoring was done as outlined in Adams et al. (2006) by assigning each student a “percent favorable” score. To find this, student responses were scored on an ordinal scale against the expert responses and given a numerical value of 1 for answers that agree with and a 0 for answers that disagree. Rather than an assigning each response to a statement (1-5) a value, this method allows for a score that is a percentage of agreement between the expert and the participant (Adams et al., 2006). Neutral responses were scored as neither agree or disagree so that the percent favorable score for a participant reflected only those statements for which they agreed with the expert.

***Interviews.*** A qualitative study with purposeful sampling and emergent coding was used to investigate student understanding of the above mentioned units of study. Interviews were conducting following the administration of the two units of study, described below. A think-aloud protocol was used to examine the student’s knowledge and problem-solving approach. Interviews were conducted as post-instruction only, during student lunch periods. Each student was interviewed separately by either the author of the study or the faculty advisor for the study. Each interview was recorded and transcribed then analyzed using emergent coding. Interviews ranged from 20-40 minutes with the average interview lasting 24 minutes.

**Think-aloud Protocol.** Students’ comprehension of course material was measured through an interview upon completion of specific units of study, defined by state standards. Upon completion of the units, a sample of students was interviewed in



each of the two PBS chemistry classes, for their understanding of the material using a think-aloud activity. Interviewers reminded students that their answers would not affect their class grade and were kept confidential.

Interviews occurred following both units of instruction and administration of the CLASS-Chem survey, in Year 1. Interviews happened during student lunch and averaged 24 minutes each. Every interview was conducted with one student at a time. Interviews were recorded and transcribed. Additionally, students completed the problem set described above by hand (see Figure 3.1). During the session, the student was asked to verbalize their thoughts and think aloud when solving the problems (Heyworth, 1999). The interviewer used probing questions to engage the student in the “think aloud” activity. Through this, the thought process used by the student and student understanding of the material were examined. Van Someren Barnard and Sandberg (as cited in Heyworth, 1999) note that this methodology provides a tool for inferring mental processes and problem-solving skills. The interviewers were careful not to ask questions that imply reasoning or guide the student’s thinking in any way. Instead, students were asked to describe what thoughts they experienced when solving the problem and were informed that there was not a correct or incorrect response. This encouraged students to express their thought processes and knowledge rather than trying to provide the “correct” answer.

## **Data Analysis**

Survey data was first scored according to the CLASS instructions (Adams et al., 2006; Barbera et al., 2008). The scoring rubric provided with the CLASS-Chem survey yielded percent favorable scores for each subcategory of questions and changes in student responses between pre- and post-test. Each of these categories was looked at for changes in overall agreement with expert responses from pre- to post-test administration of the survey. Correlated, two-tailed z-tests were used to analyze pre- and post-test data for the overall percent favorable and percent unfavorable scores. In addition, the research used z-tests for each of the nine subcategories outlined above. The nine subcategories scored were personal interest, real world connect, problem solving: general, problem solving: confidence, problem solving: sophistication, sense making/effort, conceptual connections, conceptual learning, and atomic-molecular perspective of chemistry.

Student interviews were transcribed and coded using emergent coding (Glaser & Strauss, 1967). The researcher used emergent codes to look for common responses and trends among student responses. From these themes, constituents are derived which are used to create a general description of student understanding as a result of PBS instruction. Interview data were used to inform the analysis of quantitative data.

The combination of the semi-structured interviews and the qualitative attitude surveys will be analyzed for the investigation of the effects of PBS on students enrolled in a chemistry class. As this study utilizes a post-only design, data will be looked at as expository rather than causation.

## **CHAPTER 4**

### **Data and Results**

The purpose of this study was to examine the effects of project-based science instruction in a high school chemistry classroom. Project-based science uses authentic application of content with students working in small groups to generate products that showcase learning. As knowledge acquisition is built upon using the constructivist approach (Piaget, 1964), this study will examine how well students enrolled in a PBS classroom understand and recall concepts related to units of study defined by the state standards. Additionally, since learning takes place in a real world scenario where it is seen in application, the study aims to examine any changes in students' attitudes towards chemistry while enrolled in a PBS chemistry course.

#### **CLASS-Chem Results**

Participants' answers to the CLASS-Chem survey were collected and compared to the expert responses. Statements in agreement with the experts were seen as "favorable" while statements in disagreement were seen as "unfavorable". In both pre- and post-rest, an "overall percent favorable" value is found by averaging together the percentage of favorable responses from each participant; an "overall percent unfavorable" was found with a similar method. Questions in which a student responded neutral were scored as neither agree or disagree, therefore these percentages represent strictly when the student was in agreement or disagreement with the experts. These percent favorable/unfavorable

values were also found for each of the nine subcategories listed above (See Table 4.1).

The shift in percentage from pre- to post-test was also calculated (See Figure 4.1).

Table 4.1

Year 1 CLASS-Chem results

Categories	Student-Expert agreement	Post-test 1	Post-test 2	D	s
Overall	Favorable	50.5	50.1	-0.4	3.2
	Unfavorable	24.3	22.6	-1.7	3
Personal Interest	Favorable	54.2	53.1	-1	5
	Unfavorable	21.9	19.8	-2.1	6.4
Real world Connections	Favorable	59.9	45.3	-14.6	8
	Unfavorable	15.6	32.8	17.2	6.5
Problem-Solving General	Favorable	64.4	64.6	0.2	4
	Unfavorable	12.5	15.2	2.7	2.9
Problem-Solving Confidence	Favorable	75	78.1	3.1	6.2
	Unfavorable	6.3	4.7	-1.6	1.5
Problem-Solving Sophistication	Favorable	47	57.1	10.2	4
	Unfavorable	26.8	14.3	-12.5	5.3
Sense Making/Effort	Favorable	66.4	59.7	-6.7	4.6
	Unfavorable	10.6	14.6	4	3.1
Conceptual Connections	Favorable	54.3	49.1	-5.2	6.7
	Unfavorable	23.2	13.4	-9.8	6.1
Conceptual Learning	Favorable	40.5	46	5.5	7.6
	Unfavorable	31.2	17	-14.2	7.4
Atomic-Molecular Perspective of Chemistry	Favorable	36.7	46.9	10.2	5.5
	Unfavorable	26.7	25	-1.7	6.1

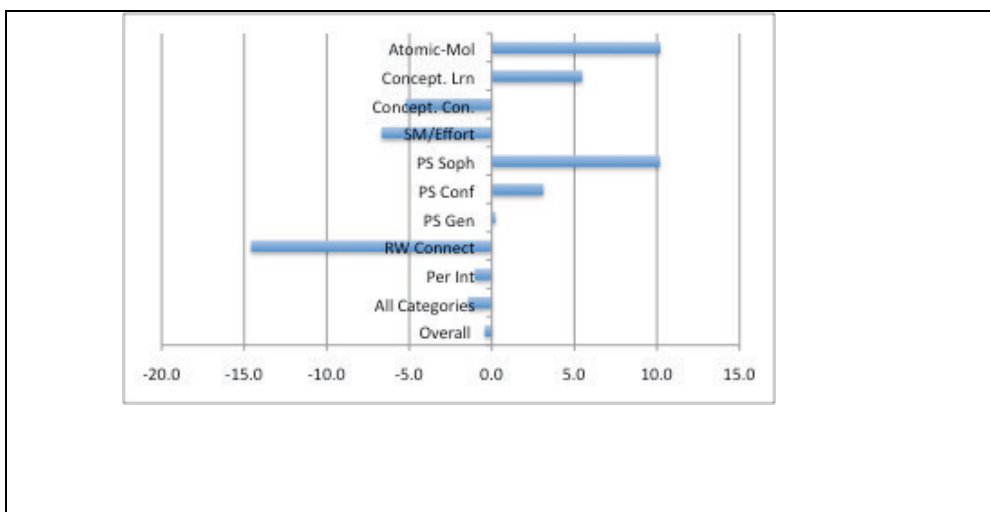


Figure 4.1. Shift in percent favorable scores for overall and subcategories

The overall percent favorable score for all responses decreased by 0.4 percent, showing a decrease in agreement with expert responses. However, a paired two-tailed z score of the percent favorable score gave a P value of 0.8961 and thus the difference between the two administrations was not significant (See Table 4.2). Similarly, the overall percent unfavorable score decreased by 1.7 percent, but z score results indicate that this is not significant ( $p = 0.5882$ ) (See Table 4.2).

Table 4.2

Z-scores and P values for overall percent favorable and unfavorable scores

	Pre-test		Post-test		Z Score	Two-tailed P value
	Mean	$\sigma$	Mean	$\sigma$		
Percent Favorable	50.53	15.05	50.10	20.67	0.07	0.90
Percent Unfavorable	24.28	12.85	22.57	10.28	0.42	0.59

Z-scores were done for pre- and post- responses in each of the nine categories (See Table 4.3). Despite a small sample size, the large standard deviation found for scores lends itself best to z-score analysis. In all categories there was only one significant shift seen: an increase in the percent of unfavorable responses for real world.

Table 4.3

Subcategories z-scores and P values

Subcategory		First post-test		Second post-test		Two-tailed Z	Two-tailed P value
		Mean	$\sigma$	Mean	$\sigma$		
Personal Interest	% Favorable	54.17	28.22	53.13	29.32	0.102	0.9188
	% Unfavorable	21.88	23.35	19.79	22.13	0.259	0.7956
Real World Connections	% Favorable	59.90	23.22	45.31	40.02	1.261	0.2077
	% Unfavorable	15.63	22.13	32.81	25.36	-2.043	0.0410
PS General	% Favorable	64.38	27.07	64.58	24.73	-0.023	0.9817
	% Unfavorable	12.50	16.12	15.21	12.94	-0.524	0.6002
PS Confidence	% Favorable	75.00	31.62	78.13	22.13	-0.324	0.7459
	% Unfavorable	6.25	14.43	4.69	13.60	0.315	0.7527
PS Sophistication	% Favorable	46.96	21.33	57.14	24.47	-1.254	0.2098
	% Unfavorable	26.79	21.43	14.29	16.50	1.849	0.0644
Sense Making/Effort	% Favorable	66.41	19.49	59.72	21.42	0.923	0.3560
	% Unfavorable	10.59	12.01	14.58	6.69	-1.162	0.2452
Content Connections	% Favorable	54.32	21.42	49.11	32.14	0.539	0.5899
	% Unfavorable	23.21	18.72	13.39	19.14	1.467	0.1424
Conceptual Learning	% Favorable	40.51	21.62	45.98	31.83	-0.569	0.5693
	% Unfavorable	31.16	22.16	16.96	21.65	1.833	0.0668
Atomic-Molecular Perspective	% Favorable	36.67	23.57	46.88	33.45	-0.998	0.3183
	% Unfavorable	30.00	23.25	25.00	21.94	0.626	0.5313

## Interview Results

Interview transcriptions were analyzed using emergent coding. Along with the interview transcription, the form that students were asked to fill out during the interview was examined. One respondent did not complete an interview form and only interview transcription was available, therefore when discussing written responses only fourteen of the total fifteen participants were analyzed. First, responses were examined for trends in approach to problems by individual questions. Next, responses were analyzed to look for overall trends in how students rationalize and solve problems of a particular unit of study.

As interviews were not explicitly geared towards student experience that lead to understanding, individual textual and structural descriptions will not be discussed. Instead, as these phenomenological aspects were seen as complimentary to the larger, quantitative piece, a composite textual and structural description for the essence of content understanding, as a result of PBS, will be drawn out of emergent coding results.

**Responses by Question.** In the following sections, student responses for individual questions are examined for patterns. Responses on the written form are examined, as well as verbal responses from the interview transcripts.

***Question 1: Water polarity.*** The first problem on the interview protocol asked students to draw a picture of a water molecule that shows the concept polarity. Overall, twelve out of fourteen participants correctly drew a water molecule that showed two small hydrogen atoms connected to a larger oxygen atom (see Figure 4.2). Of these twelve, Students B, C, E, G, I, K, J and B2 all labeled the hydrogen atoms as having a positive charge (shown with a plus sign '+') and the oxygen with a negative charge

(shown with a minus sign '-'). No distinction was made between these positive and negative charges and the partial positive and negative charges of a polar molecule. Of the students who correctly labeled the positive and negative charges, two students (E and K) represented an attraction to other polar water molecules by connecting the positive hydrogen atoms of one molecule with the negative oxygen atom of another molecule. There were four students who correctly drew a water molecule, but incorrectly showed polarity on the molecule. Of these, two students (F and C2) placed a positive on the oxygen atom and negatives on the hydrogen atoms, Student A labeled one of the hydrogen atoms with a positive charge and the other hydrogen atom with a negative charge, and one student could not recall how to show polarity. The two remaining students (F and A2) each drew a single hydrogen atom connected with two oxygen atoms.

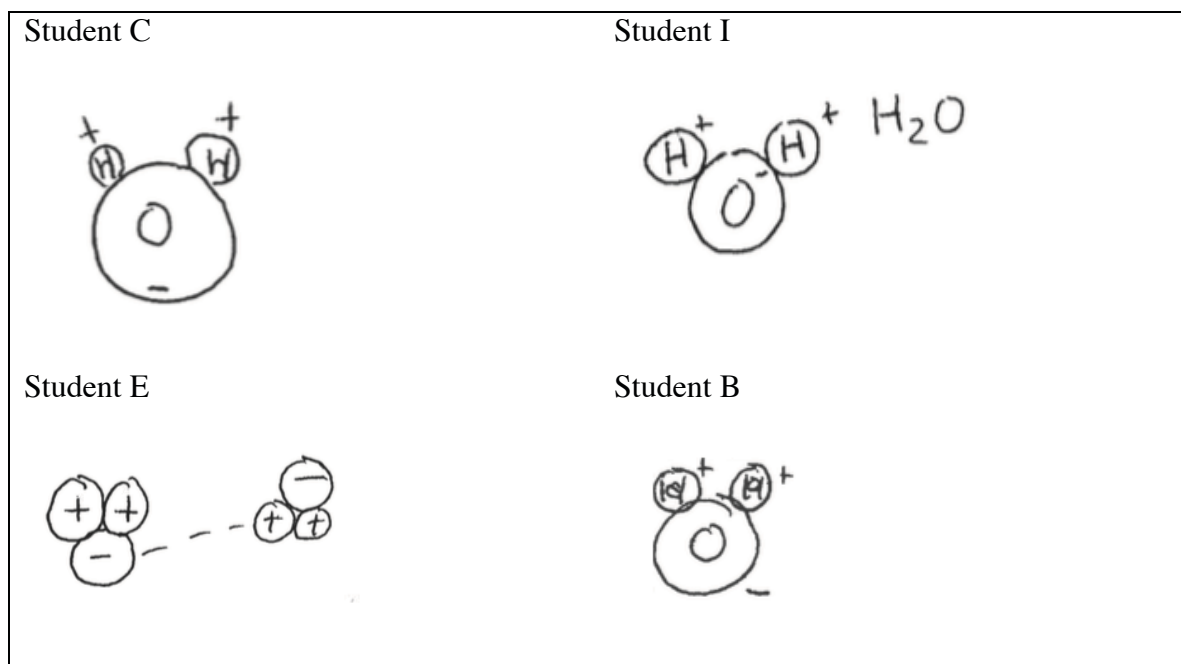


Figure 4.2. Student representations of water molecules from question 1



Two of the participants represented atoms using their chemical symbols and connected these with a line to show bonding. All of the other twelve participants represented atoms in their drawings as circles labeled with an 'H' or an 'O'. Ten of these showed the atoms in physical contact with each, similar to a space-filling representation, with all but one of these showing a bent or near-bent configuration of atoms. The remaining two simply connected the atom circles with a line to represent a bond.

Interview transcription revealed nine students out of the fifteen that verbally identified the hydrogen atoms as having a positive charge and the oxygen atom with a negative charge. However, none of the students explained how unequal sharing of electrons was causing the positive and negative charges or correctly identified them as *partial* positive and negative charges. Student B gave a typical response, "...I'm going to label it negative because oxygen in the water molecule is negative. I'm going to draw two little oxygens right here, I mean hydrogens, rather, and I'm going to label them positive"

When drawing the water molecule, five of the students (I, J, G, K and E) called the structure of the water molecule a "Mickey Mouse" shape. This was a term used by teachers to give the students a reference shape when learning about properties of water.

***Question 2: Cohesion, adhesion, and surface tension.*** Many students seemed to struggle with the second problem, which asked students to describe how the properties of water produce three different phenomena: cohesion, adhesion, and surface tension. Of all fourteen participants, eight of the participants either incorrectly labeled each term or did not write anything at all. Of those remaining six participants, Students C and E described or defined all three terms, students A and B2 correctly described two of the three terms,

and Students B and C2 only responded correctly for one of the three terms. Four of the students with correct responses (A, B, E and C2) used a picture or diagram of demonstrations done in class by their specific teacher to describe one or more the terms. Two of these eight drew a diagram of two water molecules arranged so that the oxygen atom of one water molecule is in contact with the hydrogen atoms of the other water molecule to describe the cause of surface tension. Examples of student responses are shown in Figure 4.3 below.

Interview transcriptions revealed six students (C, D, E, I, B2 and C2) who verbally explained that cohesion was the sticking together of water molecules. Student D described it as follows, “It will form a droplet, not spread everywhere. I think that’s the attraction of the molecules” Three of these students, Student D, Student B2 and Student C2, made a reference to demonstrations done in class that showed cohesion of water molecules and one student explained that an attraction of charges would cause the molecules to attach to one another. Only Student D, Student E and Student C2 correctly defined adhesion as the sticking together of different molecules. Two participants (Student A and Student D) referenced a demonstration done in the classroom. When asked to describe surface tension, Student A, Student B, Student C, Student E and Student H all referred to a net or barrier that is formed by water molecules on the surface. Eight students referenced one or more demonstrations done in the classroom. Student E stated, “Surface tension is when the water built the barrier. It’s kind of like the paperclip in the water, if I put it on the edge it will float instead of sinking because it creates the little barrier of the bonds of all the water molecules to keep it floating”.

Student C

Cohesion - sticking together of the same particles.

Adhesion - sticking together of different particles.

Surface Tension - caused by cohesion & resist external force.

Student E

Cohesion - water sticks to it's self.

Adhesion - water sticks with other things.

Surface Tension -



Figure 4.3. Student examples for question 2

**Question 3: Dissolving.** The third problem asked students to explain the process by which salt dissolves when placed in water and identify the solvent and solute of the solution. Six of the fourteen participants failed to write down a correct response, with three of these not writing anything at all. Of the remaining eight students, three of them

drew a diagram of salt and water molecules (see Figure 4.4). Student B showed salt as a single circle labeled “NaCl” surrounded by water molecules all of which are oriented so that an oxygen atom and a hydrogen atom are next to the NaCl. Student C represented salt as two circles: one labeled “Cl” with a negative sign and one labeled “Na” with a positive sign. Arrows were drawn going from the Chlorine atom to one of the hydrogen atoms on a water molecule and from the Sodium atom to the oxygen of the water molecule. Finally, Student C2’s diagram showed salt as “NaCl” in between two water molecules. The “Na” was labeled with a negative sign and an arrow was drawn towards the oxygen of one of the water molecules, which was labeled with a positive sign. The “Cl” was labeled with a negative sign and an arrow drawn towards the hydrogen side of the other water molecule, which was labeled with negative signs on each hydrogen atom.

The other five participants wrote out their responses in words (see examples in Figure 4.4). Of these, Student B2 and Student C2 correctly identified the salt as the solute and water as the solvent, while Student A2 and Student K mixed these terms up and Student A did not identify them as either on the form. Four of these five described the dissolving process as molecules or atoms being separated or broken down. Student A2 attributed the dissolving to salt being broken into increasingly smaller pieces and Student A simply said it was being separated, while Students B2 and D2 described breaking up of molecules and separating of the atoms. Only Student B2 mentioned the atoms being attracted to water molecules.

The interview transcriptions showed five students (A, D, B2, C2, and D2) who correctly identified salt as the solute and water as the solvent, while Student H, Student I

and Student A2 incorrectly switched the terms. All students except Student F, Student G, Student J, and Student K verbally described the dissolving process as the separating of salt molecules/atoms in the salt or the breaking down of salt molecules. Only one of these students, Student C2, gave a detailed explanation of salt as an ionic molecule being dissolved by a polar molecule, like water. Student B and Student E made a reference to the salt bonding with water molecules and Student H and Student C mentioned either ions or separate charges of the salt molecules. Four students (E, F, J and K) mentioned agitation and/or temperature as causing the salt to dissolve faster and of these, only Student K explained the breaking down of salt molecules as the reason for dissolving. Student D, Student G and Student I mentioned that the salt could be retrieved by evaporation and one referred to this as a physical change. Student H made a reference to a project done in class, stating, “I remember that by the mini project that we did about divers getting the bends...

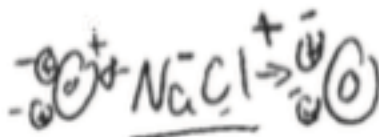
**Question 4: Polarity.** The fourth question asked for a description of polarity within a molecule such as water and the cause of this property. Of the written responses, six of the fourteen participants gave partially correct responses. Student A, Student B2, Student C2, and Student D2 described in words that positive and negative charges are due to the transfer of electrons, referring to ionic bonds. Student D2 mentioned that a polar molecule is when a positive and negative elements balance each other out for a “neutral” charge. Student K simply drew a diagram of a water molecule and labeled 2 hydrogens with a plus sign and oxygen with a negative sign. Student E simply wrote that polarity is the attraction of positive and negative charges. Nothing was written about covalent

polarity as the unequal sharing of electrons between atoms. Six of the eight who responded incorrectly to question 4 did not record a written response at all.

Student B



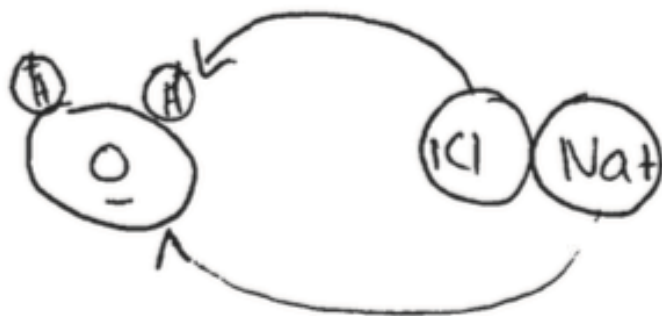
Student C2



Student E

- agitation helps w/ this process, salt breaks into smaller pieces so it's not visible.

Student C



The salt breaks down smaller and smaller and dissolves in the water. Solvent is the salt and the solute the water.

Figure 4.4- Student response examples for question 3

The interview transcriptions revealed nine of the fifteen participants (A, D, G, H, J, K, B2, D2, and C2) who described polarity as being caused by molecules having a positive and negative end, however only Student A, Student J, Student B2, Student D2, and Student C2 attributed these charges to the movement of electrons. Student A proclaimed, “It’s the amount of electrons that are given or taken away from the atoms,” and Student D2 asserted, “When an element loses an electron or gains an electron, they have a charge.” Additionally, Student J questioned, “Doesn’t that mean it has opposite sides...like positive and negative?”

Student B, Student C, and Student H mentioned or referenced electronegativity as having an impact on polarity; however only one of these described ends with opposite charges resulting from this. Student B and Student G could only recall a connection between polarity and if substances will dissolve or not, mentioning that “likes dissolve likes.”. Several students seem to associate the idea of polarity with ionic bonds only, with two students, Student A and Student C2, mentioning the term specifically.

***Question 5: Phase Changes.*** The last question prompts students to draw pictures of a microscopic view of water molecules in each of three phases. Boxes were provided with arrows labeled “Heat” connecting the three boxes. Students were additionally asked why some molecules are a gas at room temperature and others were liquid or solid. Of the fourteen interview packets completed all but two students drew molecules represented by small circles, with increasing spacing between molecules in each box starting on the left of the page. Student B, Student E and Student I used small circles to represent atoms in water molecules, while the remaining students simply used circles to represent generic

particles (see Figure 4.5). Molecule representations in the far left box were shown as very close together and confined to a specific region of the box. The middle box showed the same circles with increased space between each. The final boxes show fewer circles that are much more spaced out. Two of these twelve students (Student D and Student I) drew arrows or lines coming from the molecules in this last box to indicate motion. Several students labeled the boxes, starting on the left, as “solid”, “liquid”, and “gas”. The remaining two students (Student G and Student J) drew similar molecular representations, but in the incorrect order; both students drew liquid phase in the far left box followed by solid and then gas.

Seven of the fourteen students (A, C, E, A2, B2, C2, and D2) gave a written response to the question regarding the state of different molecules at room temperature. Students C and A2 simply attributed this phenomenon to the fact that different elements have different properties and wrote no further explanation. Student A, Student B2, and Student D2 made a reference to different substances having different melting or freezing points but gave no explanation why this is. Nor did any mention boiling or condensation points. Student C2 explained that it had to do with bonds between molecules, stating “The bonds that are formed are stronger in some substances than in other.”

Interview transcription revealed numerous patterns in verbal explanations of answer. All fifteen of the participants identified the solid phase as having molecules very closely packed together, with Student A, Student B, Student H, Student K, and Student C2 mentioning that molecules in a solid have very little movement. Student H explained, “I’m drawing them compact because that’s what makes it a solid, they’re compact.



They're not moving around a lot.” Only two described solid particles as experiencing no motion at all.

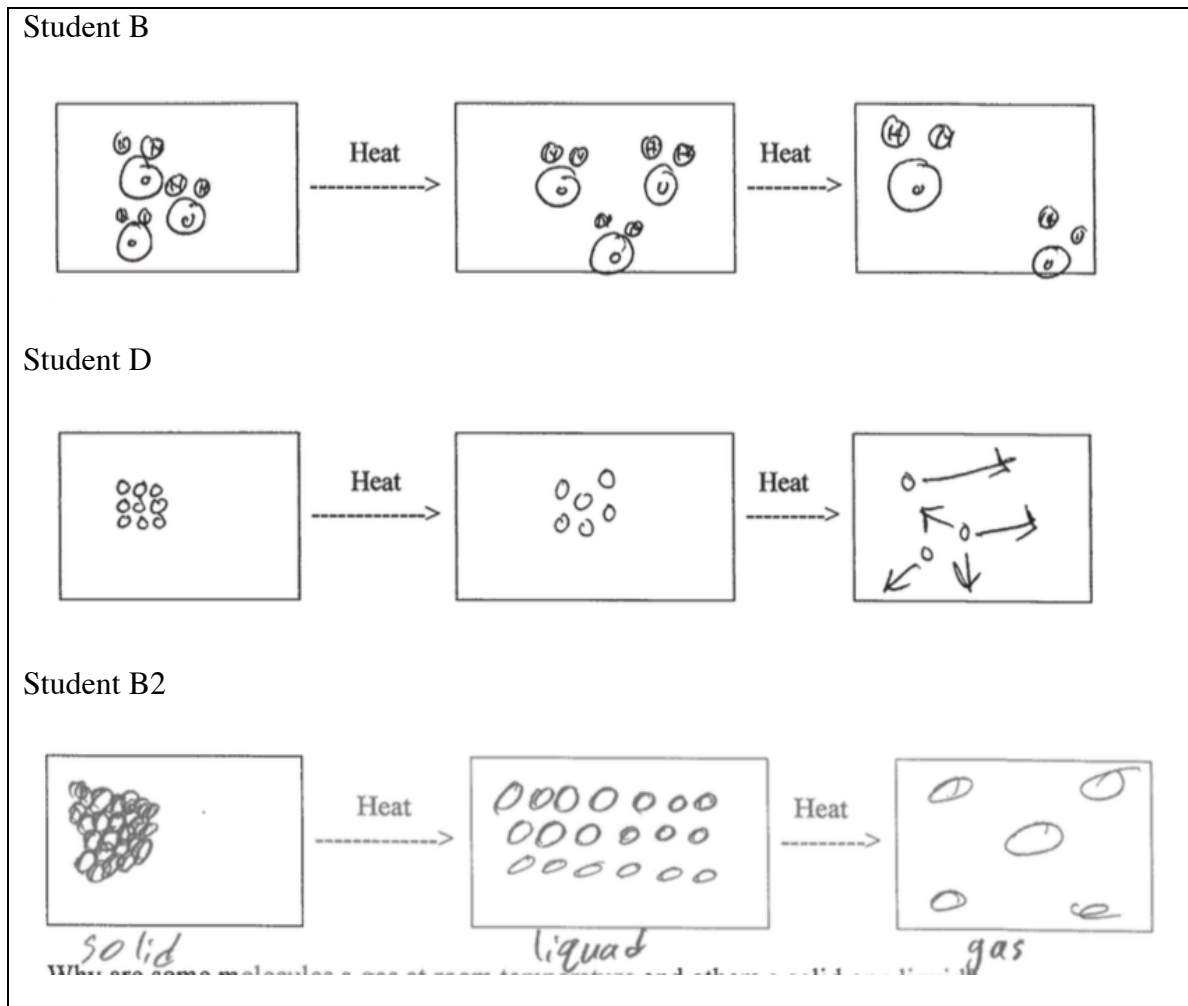


Figure 4.5- Examples of Student diagrams for Question 5

Additionally, eleven of the fifteen verbally identified molecules in a liquid as being more spread out than a solid but still rather confined; five students (C, D, G, H, and D2) remarked how a liquid will assume the shape of the container it is in. For example,

Student D asserted that the particles are “not moving that fast. They’re not necessarily stuck together completely because they take the shape of the container.”

Thirteen students described the gas phase molecules as being very spread out or all over the place, and nine students (A, B, D, F, H, I, K, B2, and C2) stated that gas molecules have a lot of movement, in relation to the other phases. When asked what causes the change in spacing and movement of molecules, Student A, Student B, Student D, Student E, Student K, and Student D2 explained that heat makes the molecules more active and one other described the increased breaking of bonds between molecules. Student B explained, “As it gets hotter and the state begins to change, they get a little bit separated and they’re allowed to move more.”

Transcriptions for the question regarding the reason certain substances are a gas at room temperature showed much less agreement in responses. Seven of the fifteen interviewed (B, C, J, A2, B2, C2, and D2) made a reference to different substances having different properties but only Student C2 elaborated on this saying that “the weaker the bonds it would be, there would be less heat required for the bonds to break.”

Student A and Student D2 mentioned different boiling points as a reason and Student E, Student I, Student B2, and Student C2 cited different melting or freezing points of different substances; however, none of these were able to explain what causes this. Two students (A and D) simply attributed this to different substances having different chemical makeup and two (Students A and D2) simply said that different substances need different temperatures to change from a solid, to a liquid and a gas.

**Overall Trends in Responses.** When responses were looked through a broader lens than question-by-question, a few notable patterns emerged. One pattern was seen in how students represent molecules in their drawings. The majority of students used small circles, often with a label of charge or chemical symbol, to represent atoms in a molecule. Circles were also used to represent molecules as a whole, when not showing specific atomic composition. Many students, whether prompted to or not, chose to use drawings or diagrams to respond on the written form. A summary of correct and incorrect responses by students is shown in Table 4.4.

Responses to the three Likert scale questions at the beginning of each interview packet showed eleven of the fourteen packets returned that ranked their understanding of chemistry as a four out of five, two ranked as a three, and one ranked as a five (See table 4.4). When scoring their understanding of the concept of polarity one participant ranked as a two, four students gave themselves a three, five of them listed four as their comfort level, and the remaining four responses all answered a five out of five. Despite nearly all accurate phase change diagrams, three students ranked their understanding of phase changes as a two, four students ranked themselves as a three, three participants scored a four, and four scored their understanding as a five out of five.

Interview transcriptions revealed a major theme of recalling demonstrations or lab experiments done during class. Many students used demonstrations to explain or elaborate their responses on several different questions, especially problems 2 and 3. Similarities were also seen in the vocabulary used with common phrases showing up in transcripts within specific problems and between them. The phrase “Mickey Mouse”

diagram showed up numerous times when talking about the shape or properties of water molecules. Additionally, all participants referred to the polar bonds in water molecules as having a negative charged end, or atom(s), and a positively charged end, or atom(s) rather than correctly describing these as a partial charge. Many responses included a reference to “properties” of the atom or substance without explaining what caused these properties.

Table 4.4

Summary of Student interview responses

Student Name	Understanding of Chemistry	Understanding of Polarity	Understanding of Phase Changes	Problem Number					
				1	2	3	4	5	6
A	4	4	5	O <sub>1</sub>	X <sub>1</sub>	X <sub>1</sub>	O <sub>1</sub>	X <sub>2</sub>	X <sub>1</sub>
B	4	4	5	X <sub>2</sub>	X <sub>1</sub>	X <sub>2</sub>	O <sub>1</sub>	X <sub>2</sub>	O <sub>1</sub>
C	4	4	4	X <sub>2</sub>	X <sub>1</sub>	X <sub>2</sub>	O <sub>1</sub>	X <sub>2</sub>	X <sub>1</sub>
D	4	3	4	O <sub>1</sub>	O <sub>1</sub>	O <sub>1</sub>	O <sub>1</sub>	X <sub>2</sub>	O <sub>1</sub>
E	4	5	3	X <sub>2</sub>	X <sub>1</sub>	X <sub>1</sub>	O <sub>1</sub>	X <sub>2</sub>	X <sub>1</sub>
F	4	4	2	O <sub>1</sub>	O <sub>1</sub>	O <sub>1</sub>	O <sub>1</sub>	X <sub>2</sub>	O <sub>1</sub>
G	4	3	3	X <sub>2</sub>	O <sub>1</sub>	O <sub>1</sub>	O <sub>1</sub>	O <sub>1</sub>	O <sub>1</sub>
I	4	5	3	X <sub>2</sub>	O <sub>1</sub>	O <sub>1</sub>	O <sub>1</sub>	X <sub>2</sub>	O <sub>1</sub>
J	4	4	3	X <sub>2</sub>	O <sub>1</sub>	O <sub>1</sub>	O <sub>1</sub>	O <sub>1</sub>	O <sub>1</sub>
K	3	3	2	X <sub>2</sub>	X <sub>1</sub>	X <sub>1</sub>	O <sub>1</sub>	X <sub>2</sub>	O <sub>1</sub>
A2	3	2	2.5	O <sub>1</sub>	O <sub>1</sub>	X <sub>1</sub>	X <sub>1</sub>	X <sub>2</sub>	X <sub>1</sub>
B2	4	3	5	X <sub>2</sub>	X <sub>1</sub>	X <sub>1</sub>	X <sub>1</sub>	X <sub>2</sub>	X <sub>1</sub>
C2	5	5	5	O <sub>1</sub>	O <sub>1</sub>	X <sub>2</sub>	O <sub>1</sub>	X <sub>2</sub>	X <sub>1</sub>
D2	4	5	4	X <sub>2</sub>	O <sub>1</sub>	X <sub>1</sub>	X <sub>1</sub>	X <sub>2</sub>	X <sub>1</sub>

*Note:* X<sub>1</sub>- correct/partial correct written; X<sub>2</sub>- correct drawing; O<sub>1</sub>- incorrect or no written response

## Summary of Results

Results presented above represent the findings of both the qualitative and quantitative aspects of this study. Investigations aimed at examining the impact of PBS on students' attitudes towards chemistry as well as understanding of chemistry concepts. Calculation of the average percent agreement and disagreement with experts showed an overall negative trend, as did overall percent unfavorable, though neither of these shifts was found to be statistically significant. Analysis for each of the subcategories showed a significant increase in the percent unfavorable scores for Real World Connections, as well as a significant decrease in the average percent unfavorable and a significant increase in the average percent favorable for Problem Solving Sophistication. Coding of the interview transcription showed a general understanding of polarity with a molecule, such as water, but little acknowledgment of the cause for polarity. However, many students were unable to explain properties resulting from polarity, such as dissolving and properties of water. Interviews also revealed a majority understanding of the relative arrangement and energy of particles among the three phases of matter. The following chapter will discuss these results and their impact on the classroom structure and pedagogy.

## **CHAPTER 5**

### **Discussion**

The purpose of this study was to investigate effects of project-based science on attitudes and understanding in a high school chemistry classroom. This two-year study consisted of a quantitative portion with support from a phenomenological piece. The qualitative investigation utilized multiple post-test only surveys designed to measure changes in students' attitudes towards learning chemistry. The quantitative portion used post-test student interviews intended to investigate PBS students' conceptual understandings and thought process in solving problems related to two units of study, as defined by the state educational standards, through state standards.

The following chapter will examine the results of the qualitative and quantitative results presented in the previous chapter. This study is framed by the following questions:

1. How are student attitudes toward chemistry affected by involvement in PBS?
2. What conceptual and procedural knowledge of chemistry concepts, specifically solutions and phase change chemistry, do students in a PBS environment gain?

The discussion of the results will be built around these questions. Specifically, as the survey used contains nine different subcategories (See Chapter 3), the discussion will look at changes that occurred in these areas as well as overall attitudes toward chemistry, following the implementation of project-based science instruction. Additionally, the

interview results will be looked at for depth of understanding and application of molecular level understanding to answer chemistry problems related to phase changes, polarity, and solutions chemistry.

### **Quantitative discussion**

The CLASS-Chem survey was used to measure students' attitudes towards learning chemistry by comparing student responses to expert responses. The survey consists of 50 statements which students rank their agreement with on a 5-pt Likert scale. Overall percent favorable and percent unfavorable scores are found for each participant by calculating the percent of statements that participants agree or disagree with the expert responses. In addition to overall scores, percent favorable and unfavorable scores were also found for each of the nine subcategories in the survey: Personal interest, Real world connections, Problem solving general, Problem solving sophistication, Problem-solving confidence, Sense-making/effort, Content connections, Conceptual learning and Atomic-Molecular Perspective.

Surveys were administered using a multiple post-test design. The first post-test took place during the beginning of the spring semester with a sample population of 33 students and the second post-test was given at the end of the semester with a sample population of 16 students. For data analysis purposes, only surveys from participants who were present for both administrations were used. The average percent favorable and percent unfavorable scores for each of the nine subcategories as well as overall scores are given in Table 4.1 in the previous chapter. Following the determination of overall percent

favorable and unfavorable scores, as well as for each of the nine subcategories, a two-tailed z-test was performed for average overall scores and each of the nine subcategories (see table 4.2 and 4.3). From this data, there was only one significant shift seen between the administrations of the survey.

Comparison of two-tailed z-scores produced an unexpected shift seen in the Real World Connections category. The average percent favorable score showed a large, though not statistically significant, decrease from post-test 1 to post-test 2. In addition to this, there was also a statistically significant increase in the average percent unfavorable score ( $p < 0.05$ ). The increase in disagreement with expert responses relating to real world connections is not consistent with the goals of PBS to immerse the student in an investigative process that is similar to that which might be done in the real world (Marx et al., 1997). The questions asked on the survey that fall into this category focus on the relationship between chemistry and everyday experiences. The overall shift towards disagreement with expert responses is seen in three out of the four questions in this category. Despite this shift, a higher percentage of students who agreed with expert responses was seen on two out the four questions. This drop contradicts research findings that involvement in PBS units can increase awareness of science's connection with future careers and application of content (Schwartz, Vye, Moore, Petrosino, Zech, & Bransford, 1998; Tseng, Chang, Lou, & Chen, 2013).

This negative trend may be associated with the defined context of the projects, which might have limited the students' views on application of the material. Students may be able to connect content knowledge with the specific context of the project used to



teach the material, thus limiting their knowledge of other applications in the real world. It may also be an issue with being able to transfer knowledge to various contexts, regardless of the material. If all knowledge acquisition within a project is with the specific content of that project, students may struggle to understand the fundamental concepts on a more general level. This could prevent them from being able to apply the same concepts within a different context.

It should be noted that the time limitations of this study did not allow for administration of the attitudes survey prior to enrollment in the PBS chemistry class. As such, the reported shifts are only representative of the second half of the school year. Longitudinal data often show more dramatic changes at the beginning or middle of a time span with a leveling off effect after a prolonged period of treatments. It may be that the window of the CLASS measures occurred after the students' attitudes towards chemistry had already shifted. Longitudinal research is needed to determine if there is an earlier shift in attitudes that might more closely correlate with prior findings from other studies or if the findings of this study point to a unique aspect of PBS chemistry instruction, namely that PBS chemistry students have greater difficulty in relating the concepts they learn to every day life than their peers in other disciplines. Additionally, there is a greater chance of type II error when the sample size is small. The lack of significant findings may be a result of small sample size.

## Qualitative Discussion

Student interviews consisted of a six problems related to phase changes and solutions chemistry, with a focus on polarity and water. During interviews, participants were asked to complete the problem set and verbalize their thought process. Questions were designed to emphasize the molecular phenomena that produce observable effects. Interviewers used probing questions to elicit student's thoughts when reading and solving chemistry problems. These interviews were recorded and transcribed then analyzed using emergent coding to find patterns in student thinking and approaches to problems.

Questions relating to the unit on solutions chemistry involved drawing pictures and describing chemical phenomena such as polarity, properties of water, and the dissolving process. Many students seem to associate the idea of polarity with a transfer of electrons as in an ionic bond, rather than an unequal sharing of electrons that occurs in polar covalent. Students were familiar with the idea that a molecule being polar meant there was a positive end and a negative end, however those that were able to give reasoning for this attributed it to the loss or gain of electrons. This may have been caused by terminology confusion, as several students associated charges of polarity with the transfer of electrons found in ionic bonds.

Most students (twelve out of fourteen) were able to correctly draw a diagram of a water molecule showing polarity, with a positive charge on two hydrogen atoms and a negative charge on the oxygen atom however none of the students were able to explain what was causing this. All students represented the atoms within a water molecule by using circles, similar to a two-dimensional space-filling model. It is unclear if student

perceived the shapes of these atoms within the molecule as being rounded like a circle as they drew, or if this was merely used to represent space occupied by the subatomic particles of each atom. All students, including the two that incorrectly labeled the charges due to polarity, drew the molecule as a bent structure. Several students used common vocabulary when describing the shape of the water molecule, calling it a “Mickey Mouse” structure. This is a term used by both teachers to help students draw a connection to the conformational structure of the molecule. No students explained what caused this bent shape, though.

This pattern was continued when students were asked to describe phenomena associated with properties of water: cohesion, adhesion, and surface tension. Majority of students were unable to recall the definition or meaning of these terms. Only one of the students was able to explain that an attraction of charges on adjacent water molecules caused phenomena like cohesion and surface tension. Numerous students described surface tension as a net or barrier formed by attraction of water molecules. Numerous students, even if unable to recall the meaning of these terms, were able to recall demonstrations done in class. This highlights the importance of chemical demonstrations to the storage of knowledge and the development of understanding, through the constructivist approach. Even if they were unable to remember the correct definition, students were able to describe what occurred in classroom demonstrations designed to give examples of these terms. It should be noted that these properties were not a main focus of projects in neither Year 1 nor Year 2. Therefore, without the in-depth exposure of a full project, students seem to only recall pieces of the information.

When asked to explain the process by which salt dissolves in water, over half of the participants correctly described, either through words or diagrams, the breaking up salt particles due to attraction to the charges on water molecules. Some students described this process as merely separating out salt molecules while three of the participants that answered the question described the breaking apart of atoms. All students with correct response gave some acknowledgment of a negatively charged chlorine atom being attracted to the positive hydrogen atoms of a water molecule and the attraction of the positively charged sodium and the negatively charged oxygen atom of a water molecule. As with the polarity diagram, students used circles labeled with the chemical symbols of the elements to represent atoms in the two different molecules. As before, students seem to be able to recall a general cause of the phenomenon without giving an explanation of how this is produced.

The question regarding phase changes asked participants to draw a molecular representation of the three different phases of matter in boxes provided. Most student drawings appeared fairly similar, with particles represented by small circles, with the exception of two students who used water molecules in which circles were used to represent individual atoms within the molecule. All students represented the solid phase by showing particles packed closely together in a set shape, and many were able to explain this is because they have very little energy and thus little to no movement. No students identified this as thermal energy and two students explained that there was no movement at all by the particles in the solid phase. Of the students who identified that there was a small amount of movement among the particles, none of them identified this

as vibrational energy. Students similarly were able to explain that as heat was added the particles became more energetic and began to move around more in the liquid phase before becoming a gas and being highly energetic.

The diagrams drawn represent content that is present in both the high school chemistry state standards, as well as the eighth grade science standards, so it is possible that some of this knowledge was acquired prior to enrollment in the PBS course. However, the idea of increased energy and motion causing the different properties of each phase is one that was explored directly through activities within the projects used in each class. Specifically, during instruction students not only drew out and described particles from each phase but also acted out the energy and motion of these particles. In projects from both years, students were asked to describe the cause of observable properties for each phase as well as phase changes, in terms of particle activity.

**Composite Textual Description of Student Understandings.** Student perceptions of the molecular phenomena examined were rooted in conceptual representations and experiences. All of the participants in the study chose to represent particles as round objects of varying size. This decision reflects the representations commonly seen in science classrooms and educational texts. These representations, in the form of drawings, reflected accurate content knowledge in relation to relative size of atoms of different elements, as well as spatial arrangement within a molecule such as water. This common representation method is related back to examples seen during projects, as students often recalled how it was done previously. Consistent representations used by the teacher and students within a project were reinforced with the

students. As a result, representations became innate for students, which allowed for accurate depictions of chemical phenomena. Research supports these findings that knowledge of symbolic representation is important for understanding concepts in chemistry (Abdo & Taber, 2009).

The thought processes displayed when attempting to explain scientific phenomena relied heavily on teacher-demonstrations or student experiments that occurred as part of project investigations. Participants able to recall these experiences in class gave a description of how the phenomenon being investigated is represented through the observations in the activity. Indeed, both classroom demos and student-centered lab work with in the projects require students to generate an explanation of macroscopic observations based on molecular properties. In other words, students were asked to explain the cause of the observed property on the molecular level. As many studies have shown, in order to fully comprehend concepts in chemistry, students must be able to connect the three levels of understanding (Devetak et al., 2009; Heyworth, 1999; Rappoport & Ashkenazi, 2008).

Understandings regarding phase changes were congruent with the expectations and rigor of the standards. Students' awareness of spatial arrangement between each phase of matter is consistent with content knowledge presented during the projects. However, inconsistency was displayed in understanding of the cause of these structural changes on the molecular level. Many participants failed to acknowledge the role of thermal energy in the change from one phase to another. The solutions and polarity portions of the interview problem set also revealed a general understanding of concepts

without being able to give much explanation of the cause on the molecular level. This supports the findings of Abdo et al. (2009), who found that students were able to represent the arrangement of molecules in the phases of matter, but neglected to acknowledge the thermal motion of these molecules. Again, terminology and representation was mostly consistent with course expectations, as defined by the standards. However, many students confused the uneven sharing of electrons between two elements in a polar bond with the transfer of electrons in an ionic bond.

**Composite Structural Description.** Throughout all of the interviews and for each question asked, it seemed that many students were able to recall information based on activities or demonstrations done during a project. Participants consistently referenced instructional activities, known as scaffolding, meant to guide student learning and enhance investigations rather than deliver information directly. Only a few students ever referenced the actual context of a specific project that was used to teach the material. This shows that students may form mental schema through experience and observation of chemical phenomena, rather than the production of culminating artifacts. Weeks or months after completing projects, the activities in which students could observe macroscopic effects of molecular interactions and properties are what seem to help them recall information the best. As knowledge of a subject is dependent on the experiences with that topic, the importance of activities like this in a PBS unit that support student understanding of content, emerges as an essence of PBS (Moustakas, 1994). A focus on experiencing the content through PBS may help students draw connections between content being covered in a unit and observable examples of that content. This in turn may

be stored in a specific scheme of knowledge that was developed during the course of the project. For example, previous experiences with water may have given students observations of properties such as surface tension, cohesion and adhesion, prior to learning the chemical reasoning behind them. As this prior knowledge is not framed scientifically, when these concepts were explained on a molecular level while observing the phenomena, students were able to assimilate the information and store it in their memory. This could be critical for future chemical instruction, in both PBS and other educational settings, as a heavy emphasis should be placed on laboratory experiments and demonstrations in order for students to gain a deeper understanding of the content.

The ability to recall general information but the inability to give an in-depth explanation of the cause for the properties that were described is contradictory to the knowledge the is gained through a student-centered, inquiry investigation of a PBS unit (Krajcik et al., 1999). There is a chance that students were hesitant to go in-depth with reasoning for fear of being incorrect in front of the interviewer. Since the primary interviewer was either a student teacher or teacher for all of the participants, there may have been a feeling by some students that their responses could somehow influence their performance in the classroom, despite being assured that there was no connection between the classroom grades and their responses. Indeed, many participants displayed hesitation or reluctance when giving verbal responses and several attempted to receive feedback on the correctness of their response. Another cause may have been the depth of understanding necessary for the production and presentation of the final artifact from the projects. The level of understanding demonstrated in the student interviews was



reasonable for the state standards, which were used to assess student work. Therefore, it may be that the project design did not require students to delve deep enough in to the content and gain further understanding.

## CHAPTER 6

### Conclusions and Implications

The above study aimed at investigating the influence of project-based science on high school students' attitudes towards chemistry and understanding of chemistry concepts. A multi-post design was used with a quantitative attitudes survey to measure changes in student attitudes towards chemistry and learning chemistry over the course of a semester enrolled in a PBS chemistry course. Two-tailed Z-scores and P values were used to examine changes that occurred in student attitudes. The qualitative aspect of this study utilized a post-interview only design with semi-structured interviews to investigate student's understanding of chemistry concepts and thought-process when solving chemistry problems related to two units of study, as defined by the state standards. Data analysis for the qualitative portion involved emergent coding of interview transcriptions and written responses of participants.

Results of the study revealed a decrease in the average percent agreement and disagreement with experts, as did overall percent unfavorable, though neither of these shifts was found to be statistically significant. Analysis for each of the subcategories showed a significant increase in the percent unfavorable scores for Real World Connections ( $p < 0.05$ ) and though other notable shifts were seen, none were found to be significant. Coding of the interview transcriptions showed a general understanding of polarity with a molecule, such as water, but little acknowledgment of the cause for polarity. Interviews also revealed a majority understanding of the arrangement and

energy of particles between the three phases of matter. A pattern of information recall involving demonstrations done during class was also prevalent. Phenomenological reduction revealed a reliance on experience and representations used during projects to recall information and a lack of in-depth reasoning to explain concepts.

### **Limitations**

This study was constrained initially by the researcher's lack of access to students at the beginning of the school year. IRB approval was obtained late in the Fall semester preventing the researcher from collecting CLASS data before unit 1. Thus the CLASS results only measure attitude changes for a small portion of the students' PBS experience, namely shifts that occurred in the Spring semester. Potential shifts that occurred in the Fall semester were not measured as part of this study. Moreover, the CLASS posttest was administered at a stressful time in the semester. It may be that student attitudes towards chemistry decline just before final exams. Additionally, small sample size may have resulted in type II error. It is more difficult to find significance with small sample sizes and so the chances of falsely accepting the null hypothesis increase.

### **Suggestions for future research**

Future research should seek to investigate more in-depth questions involving student attitudes towards chemistry and the specific skills associated with subcategories like those examined in the CLASS-Chem survey. The decrease in alignment between student and expert responses in Real World Connections will need to be looked more directly and with a larger sample size to gauge the effectiveness of PBS for emerging

students in authentic problems like those seen in the real world. As this is a fundamental property of PBS, it is important to determine the depth to which this is achieved or if these results were unique to this sample or if this is an issue in Chemistry. Additionally, other skill sets associated with PBS such as problem-solving and molecular view should be looked at to determine if goals for this instructional method are truly being met in a chemistry classroom. Instrumentation designed specifically to target these skills could provide a more in-depth understanding of the effect of PBS instruction.

A true pre- and post-test CLASS may reveal more significant and expected shifts in attitudes over the course of the year, as the time frame used for this study did not account for student attitudes prior to entering the PBS classroom. A longitudinal, pre-test multiple post-test study could offer insights into when, if ever, shifts in chemistry attitudes occur. Additionally, as this study had a small sample size, a more comprehensive view of student attitudes could be found with a larger sample size. A larger sample would also allow for more generalizability of results.

Additional future research could look more longitudinally at student learning of content throughout the course of projects in specific units to better understand how students construct knowledge throughout the course of a project investigation. Research may also be concerned with examining student comprehension as a result of PBS units through experimental design studies. It is important to understand how students construct knowledge and what depth of understanding can be gained as a result of PBS. If investigations are structured properly and driven by students, it may be the case that an applicable knowledge of content is gained rather than one that is defined by education

standards. A quasi-experimental approach could be utilized here in order to compare the understanding of content between a PBS class and class that is more teacher-centered and lecture-based. Alternatively, instrumentation designed to probe more in-depth knowledge and require molecular explanations could provide insight into the level of comprehension that students in PBS obtain. A more thorough phenomenological investigation could also target specific components of PBS units that lead to deeper student understandings. These results could help guide future practitioners of PBS to foster better investigation and knowledge construction.

### **Implications and Conclusions**

The lack of significant shifts in attitudes scores may be attributed to the low sample size used for the quantitative portion or to the short duration of treatment between the pre- and post-tests. As this was a very small sample for a quantitative study, the results may not be applicable to a wider population and as such may not be truly representative of project-based science as a whole. However, the shifts seen do raise important aspects of PBS that should be further examined. Particularly, Real World Connections and Problem Solving are of importance as they represent fundamental concepts of the theoretical framework that forms the foundation for PBS.

It is unclear if the understanding displayed through student interviews is a result of the PBS or similar instructional activities. As most students referenced demonstrations or activities done in the classroom, rather than projects or contexts associated with projects, students may not be making connections between the content and the context.

However, consistency of comprehension levels suggests that the project units used were able to develop sufficient understanding of chemistry concepts as defined by state standards, despite many students not being able to explain cause for molecular phenomena.

Project-based science offers unique opportunities to immerse students in collaborative investigations that involve authentic application of course content. The above study examined changes in student attitudes towards the subject of chemistry as well as understanding of chemistry content investigated through PBS units.

## REFERENCES

- Adams, W. K., Perkins, K. K., Podolefsky, N. S., Dubson, M., Dubson, N., & Wieman, C. E. (2006). New instrument for measuring student beliefs about physics and learning physics: The Colorado learning attitudes about science survey. *Physical Review Special Topics- Physics Education Research*, 2, 2-15.
- Adbo, K., & Taber, K. S. (2009). Learners' mental models of the particle nature of matter: A study of 16-year-old Swedish science students. *International Journal of Science Education*, 61(6), 757-786.
- Alrehaly, E. D. (2011). *Parental attitudes and the effects of ethnicity: How they influence children's attitudes towards science education*. Retrieved from ERIC Database. (ED515978).
- American Association for the Advancement of Science (2009). *Project 2061: Benchmarks for science literacy*. New York: Oxford University Press. Retrieved from <http://www.project2061.org/publications/bsl/online/index.php>.
- Barbera, J., Adams, W. K., Wieman, C. E., & Perkins, K.K (2008). Modifying and validating the Colorado learning attitudes about science survey for use in chemistry. *Journal of Chemical Education*, 85(10), 1435-1439.
- Baseya, J. M., & Francis, C. D. (2011). Design of inquiry-oriented science labs: Impact on students' attitudes. *Research in Science & Technological Education*, 29(3), 241-255.
- Bauer, C. F. (2005). Beyond "student attitudes": Chemistry self-concept inventory for assessment of the affective component of student learning. *Journal of Chemical Education*, 82(12), 1864-1870.
- Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The Qualitative Report*, 13(4), 544-559.

- Bennett, J., & Hogarth, S. (2009). Would you want to talk to a scientist at a party? High school students' attitudes to school science and to science. *International Journal of Science Education*, 31(14), 1975-1998.
- Berg, C. A. R., Bergendahl, V. C. B., & Lundberg, B. K. S. (2003). Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment. *International Journal of Science Education*, 25(3), 351-372.
- Blalock, C. J., Lichtenstein, M. J., Owen, S., Pruski, L., Marshall, C., & Toeperrwein, M. (2008). In pursuit of validity: A comprehensive review of science attitudes instruments 1935-2005. *International Journal of Science Education*, 30(7), 961-977.
- Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist*, 26(3&4), 369-398.
- Brooks, J. G., & Brooks, M. G. (2001). *In search of understanding: The case for constructivist classrooms*. Upper Saddle River, NJ: Merrill Prentice Hall.
- Calik, M. (2008). Facilitating students' conceptual understanding of boiling using a four-step constructivist teaching method. *Research in Science and Technological Education*, 26(1), 59-74.
- Calik, M., & Ayas, A. (2005). A cross-age study on the understanding of chemical solutions and their components. *International Education Journal*, 6(1), 30-41.
- Carr, M. (1984). Model confusion in chemistry. *Research in Science Education*, 14, 97-103.
- Cokelez, A. (2010). A comparative study of French and Turkish students' ideas on acid-base reactions. *Journal of Chemical Education*, 81(1), 102-106.
- Colley, K (2008). Performance-based assessment. *The Science Teacher*, 75(8), 68-72.



- Cooper, M. M. (2005). An introduction to small-group learning. In Pienta, N.J., Cooper, M. M., & Greenbowe, T. J. (Eds.) *Chemists' guide to effective teaching* (pp. 117-128). Upper Saddle River, NJ: Pearson Prentice Hall.
- Devetak, I., Vogrinc, J., & Glazar, S. A. (2009). Assessing 16-year-old students' understanding of aqueous solution at submicroscopic level. *Research in Science Education*, 39, 157-179.
- Dewey, J. F. (1938). *Experience and education*. Indianapolis: Kappa Delta Pi.
- Dickinson, G., & Jackson, J. K. (2008). Planning for success: How to design and implement project-based science activities. *The Science Teacher*, 175(8), 29-32.
- Dickinson, G., Summers, E. J., & Jackson, J. K. (2010). Developing expertise in project-based science: A longitudinal study of teacher preparation and student perceptions. In Yager, R. E. (Ed.), *Exemplary science for resolving societal challenges* (pp. 1-17). Arlington, VA: National Science Teachers Association Press.
- Fishbein, M. (1963). An investigation of the relationships between beliefs about an object and the attitude toward that object. *Human Relations*, 16(3), 233-238.
- Fraenkel, J. R., & Wallen, N. E. (2009). *How to design and evaluate research in education*. New York: McGraw-Hill Higher Education.
- Froschauer, L. (2006). How can we attract students to STEM careers? *NSTA Reports*. Arlington, VA: National Science Teachers Association Retrieved from <http://www.nsta.org/publications/news/story.aspx?id=52862>.
- Gabel, D. L., Samuel, K. V., & Hunn, D. (1987). Understanding the particulate nature of matter. *Journal of Chemical Education*, 64(8), 695-697.
- Grove, N., & Bretz, S. L. (2007). CHEMX: An instrument to assess students' cognitive expectations for learning chemistry. *Journal of Chemical Education*, 84(9), 1524-1529.

- Hand, B. M., & Treagust, D. F. (1988). Application of a conceptual conflict teaching strategy to enhance student learning of acids and bases. *Research in Science Education*, 18, 53-63.
- Hansen, M., & Gonzalez, T. (2014). Investigating the relationship between STEM learning principles and student achievement in math and science. *American Journal of Education*, 120(2), 139-171.
- Heyworth, R. M. (1999). Procedural and conceptual knowledge of expert and novice students for the solving of a basic problem in chemistry. *International Journal of Science Education*, 21(2), 195-211.
- Hinton, M. E., & Nakhleh, M. B. (1999). Students' microscopic, macroscopic, and symbolic representations of chemical reactions. *Chemistry Education*, 4(5), 158-167.
- H. R. 1804–103rd Congress: Goals 2000: Educate America Act. 1993. In GovTrack.us (database of federal legislation). [www.govtrack.us/congress/bill.xpd?bill=h103-1804](http://www.govtrack.us/congress/bill.xpd?bill=h103-1804).
- Jasien, P. G. (2013). Roles of terminology, experience, and energy concepts in student conceptions of freezing and boiling. *Journal of Chemical Education*, 90, 1609-1615.
- Johnson, D. W., Johnson, R. T., & Roseth, C. (2010). Cooperative learning in middle schools interrelationship of relationships and achievement. *Middle Grades Research Journal*, 5(1), 1-18.
- Johnson, D. W., Johnson, R. T., & Smith, K. (2007). The state of cooperative learning in postsecondary and professional settings. *Educational Psychology Review*, 19(1), 15-29.
- Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, 7, 75-83.

- Kanter, D. E., & Konstantopoulos, S. (2010). The impact of a project-based science curriculum on minority achievement, attitudes, and careers: The effects of teacher content and pedagogical content knowledge and inquiry-based practices. *Science Education*, 94(5), 855-887.
- Karaçalli, S., & Korur, F. (2014). The effects of project-based learning on students' academic achievement, attitude, and retention of knowledge: The subject of 'Electricity in our lives'. *School Science & Mathematics*, 114(5), 224-235. doi:10.1111/ssm.12071.
- Kirkpatrick, W. H. (1918). The project method. *Teachers College Record*, 19(4), 319-335.
- Krajcik, J. S. (2015). Project-based science. *Science Teacher*, 82(1), 25-27.
- Krajcik, J., Czerniak, C., & Berger, C. (1999). *Teaching Children Science A Project-based Approach*. Dubuque, IZ: McGraw-Hill.
- Krajcik, J. S., McNeil, K. L., & Reiser, B. J. (2008). Learning-goals-driven design model: Developing curriculum materials that align with national standards and incorporate a project-based pedagogy. *Science Education*, 92(1), 1-32.
- Kukla, A. (2000). *Social Constructivism and the Philosophy of Science*. London: Routledge.
- Ladewski, B. G., Krajcik, J. S., & Harvey, C. L. (1994). A middle grade science teacher's emerging understanding of project-based instruction. *The Elementary School Journal*, 94(5), 499-515.
- Liu, X. (2007). Elementary to high school students' growth over an academic year in understanding the concept of matter. *Journal of Chemical Education*, 84(11), 1853-1856).
- Mager, R. F. (1984). *Developing attitude toward learning*. Belmont, CA: David S. Lake Publishers.

- Marx, R. W., Blumenfeld, P.C., Krajcik, J. S., Soloway, E. (1997). Enacting project-based science. *The Elementary School Journal*, 97(4), 341-358.
- Moustakas, C. (1994). *Phenomenological research methods*. Thousand Oaks, CA: Sage Publications Inc.
- Nakhelh, M. B. (1992). Why some students don't learn chemistry: Chemical misconceptions. *Journal of Chemical Education*, 69(3), 191-196.
- Nakhelh, M. B. (1994). Students' models of matter in the context of acid-base chemistry. *Journal of Chemical Education*, 71(6), 495-499.
- NGSS Lead States. 2013. *Next generation science standards: For states, by states*. Washington, DC: National Academies Press.
- Ornstein, A. O. (2006). The frequency of hands-on experimentation and student attitudes toward science: A statistically significant relation (2005-51-Ornstein). *Journal of Science Education & Technology*, 15(3/4), 285-297.
- Ozman, H. (2013). A cross-national review of the studies on the particulate nature of matter and related concepts. *Eurasian Journal of Physics and Chemistry Education*, 5(2), 81-110.
- Piaget, J. (1964). Development and learning. *Journal of Research in Science Teaching*, 2(3), 176-186.
- Polman, J. L. (2000). *Designing project-based science: connecting learners through guided inquiry*. New York: Teachers College Press.
- Rappoport, L. T., & Ashkenazi, G. (2008). Connecting levels of representation: Emergent versus submergent perspective. *International Journal of Science Education*, 30(12), 1585-1603.
- Raved, L., & Assaraf, O. (2011). Attitudes towards science learning among 10<sup>th</sup> grade students: A qualitative look. *International Journal of Science Education*, 33(9), 1219-1243.

- Rivet, A. E., & Krajcik, J. S. (2004). Achieving standards in urban systematic reform: An example of a sixth grade project-based science curriculum. *Journal of Research in Science Teaching*, 41(7), 669-692.
- Robinson, M., & Ochs, G. T. (2008). Determining why students take more science than required in high school. *Bulletin of Science, Technology, and Society*, 28(4), 338-348.
- Sadi, O., & Cakiroglu, J. (2011). Effects of hands-on activity enriched instruction on students' achievement and attitudes towards science. *Journal of Baltic Science Education*, 10(2), 87-97.
- Schmidt, H. J., & Chemie, F. (1995). Applying the concept of conjugation to the Bronsted theory of acid-base reactions by senior high school students in Germany. *International Journal of Science Education*, 17(6), 733-741.
- Scott, C. A. (1994). Project-based science: Reflections of a middle school teacher. *The Elementary School Journal*, 95(1), 75-94.
- Schneider, R. M., Krajcik, J. S., Marx, R. W., & Soloway, E. (2002). Performance of students in project-based science classrooms on a national measure of science achievement. *Journal of Research in Science Teaching*, 39(5), 410-422.
- Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., & Bransford, J. D. (1998). Doing with understanding: Lessons from research on problem- and project-based learning. *The Journal of the Learning Sciences*, 7(3&4), 271-311.
- Seidman, I. (1998). *Interviewing as qualitative research: A guide for researchers in education and the social sciences*. New York: Teachers College Press.
- Toolin, R. E. (2004). Striking a balance between innovation and standards: A study of teachers implementing project-based approaches to teaching science. *Journal of Science Education*, 13(2), 179-187.

Tseng, K. G., Chang, C. S., Lou, S. I., & Chen, W. (2013). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal Of Technology & Design Education*, 23(1), 87-102.

Vygotsky, L. S. (1962). *Thought and language*. Cambridge, MA: MIT Press.

Wink, D. J. (2006). Connections between pedagogical and epistemological constructivism: Questions for teaching and research in chemistry. *Foundations of Chemistry*, 8, 111-115.

Yin, R. K. (2003). *Case study research: design and methods* (3<sup>rd</sup> ed.). Thousand Oaks, CA: Sage.