# PROBLEM BASED LEARNING AND THE SCIENTIFIC PROCESS

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ABSTRACT

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This research project was developed to inspire students to constructively use problem based learning and the scientific process to learn middle school science content. The student population in this study consisted of male and female seventh grade students. Students were presented with authentic problems that are connected to physical and chemical properties of matter. The intent of the study was to have students use the scientific process of looking at existing knowledge, generating learning issues or questions about the problems, and then developing a course of action to research and design experiments to model resolutions to the authentic problems. It was expected that students would improve their ability to actively engage with others in a problem solving process to achieve a deeper understanding of Michigan's 7$^{th}$ Grade Level Content Expectations, the Next Generation Science Standards, and a scientific process. Problem based learning was statistically effective in students' learning of the scientific process. Students statistically showed improvement on pre to posttest scores. The teaching method of Problem Based Learning was effective for seventh grade science students at Dowagiac Middle School.

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## Introduction

**Rationale/Problem**

Secondary science education today can often be looked at as a challenge to many students in both middle school, and high school. For many years, educators have been searching for ways to deepen the science understanding of students through multiple teaching methods from direct teacher application and direct instruction to student centered inquiry based models. The motivation of a student can greatly increase the amount of control over their learning simply due to the interest level and heightened attention to the topic (Ferreira and Trudel 2012). Also, the more a student can make a real life connection to the content, the more the student will be motivated to understand and retain that content. In order to fully engage in learning, students must have an internal or external motivation towards what they are learning. The method of Problem Based Learning (PBL) can be used within education to achieve a high level of student engagement (Williams et al. 2009).

This research project focused attention on using a student centered model of Problem-Base Learning to increase comprehension and depth of knowledge of science content using the scientific process. Problem Based Learning within this study used carefully written, ill-structured problems to deepen understanding and set in place a guide for a process of problem solving. In combination with the PBL method, a structured scientific process was used to help guide students to learning Michigan State standards related to chemical and physical changes in matter.

According to findings of David Jonassen (1997) though, “the uses of ill-structured problems, students are able to possess multiple solutions, solution paths, fewer parameters which are less manipulable and contain uncertainty about which concepts, rules, and principals are necessary for a solution or how they are organized and which solution is best"(Jonassen 1997). Research findings from Shelagh Gallagher and colleagues (1995) showed that ill-structured problems "provide a firm attachment to the real world" and allowed for many pathways of learning to be explored. Being able to give students multiple ways to learn allowed them to deepen understanding and also forces them to take ownership of their learning to problem solve the best solution, through multiple solutions to the same problem (Laxman 2013).

In middle schools and high schools across the country many teachers use the pacing guide of a text book to give them sample questions to ask students before, during, and after the units are completed. These types of questions, according to Jonassen (1997), are considered to be "well-structured" problems. These are questions that are designed to engage the student, present elements of a problem as well as defined answers that would be expected of students to achieve through their learning. These are more content specific and have clear defined right and wrong answers. Developing questions either by the teacher (more scaffolded learning) or the student (less scaffolded learning) based on prior knowledge and interest in Problem Based Learning pushed children to come up with multiple solutions and path ways to the answer (Belland and Richardson 2010, Dahlgren et. al 2001). In this research study at Dowagiac Middle school it was intended for students to solve ill structured problems first with the help of a teacher through scaffolded inquiry, and then more independently on their own. The questions created in this PBL format were not created from textbooks, but rather questions related to everyday life.

Teachers strive to keep the attention of students in order to increase their learning. By using Problem Based Learning students are more engaged, due to the connection to real life subject matter. When students are making a connection to the topics discussed in class, they gain curiosity and begin to develop interest into furthering their own investigation. A student who continues to build ownership of their own learning will be intrinsically motivated to push themselves to deepen their thinking based on their own curiosity and inner drive. Having ill-structured problems that relate and connect to their everyday lives has a positive impact on a students learning. General K-12 education teachers have been using PBL formats for decades, although the first students of PBL were not young adolescents, but rather medical students.

The Problem Based Learning strategy has been used since the 1960's in medical schools. McMaster University in Ontario used PBL in training of Physicians (Williams et al. 2009). Their Project for Learning Resources Design PBL format developed clinical reasoning skills. The initial design of PBL for medical schools was extensively studied by Dr. Howard Barrows of McMaster University (Kaufman 1985). Barrows recognized young physicians were graduating with a plentitude of knowledge and information without the critical reasoning skills to use the information (Gallagher et al. 1995). Maastrict University in the Netherland and the University of Newcastle in Australia were also front runners in the foundations of Problem Based Learning for medical students (Kaufman 1985). Today, Maastrict University is one of the front runners in PBL education, adopting the PBL format for all of its 16,000 students and 4,000 educators within the University (Our Profile, 2014)

In the 1980s and 1990's onward there was a transition from PBL use in medical schools to undergraduate sciences, such as entry level biology, chemistry, physics, and engineering

(Gürses et al 2007, Raine and Symons 2005, Rossiter and Biggs 2008, Williams et al. 2009). Many studies have been done comparing Problem Based Learning vs. standard lecture based entry level college courses, Results and comparison will be explained further in detail later in this thesis.

**What is PBL?**

Problem based learning can be used in a variety of levels of student centered vs teacher centered. Depending on the teacher's specific teaching methods and styles, problem based learning will look different in every classroom. Key factors are the age of students and the amount of practice students have had using the problem based learning format. In the study *Toward A Theory of Teaching in Context* by Alan H. Schoenfeld (1998), two explicit teaching styles of expert and novice teachers were analyzed to see the difference between a novice teachers' basic teaching style of textbook driven questions compared to problem centered discussions from expert teachers. A typical novice teacher may use this traditional method of direct teacher instruction of questions generated from the teacher and answers generated from the students' findings in textbooks (Hmelo-Silver and Barrows 2006). This method of teaching is teacher directed learning, where known answers are expected to be achieved by the students in a timely manner. Direct instruction does not give much room for students to divert from the original learning plan and make additional connections to the topic, in contrast to a problem based learning method. The goal of PBL is to have students to be aware of their own thinking and learning (Hmelo-Silver and Barrows 2006). According to the Schoenfeld study and the educators, those who use inquiry have "higher levels of learning as well as remembering facts" in classrooms and "having students learn what questions to ask, how to make predictions from theories, and how theories and rules can be tested," helps students learn (Shoenfeld 1998).

The research study reported here at Dowagiac Middle School demonstrated directly this method of teaching where students were held accountable for their learning by generating their questions in order to develop a hypothesis, test their hypothesis, and generate a learning experiment to back up their thinking to solve a real world problem. The intent of this research study was to develop the problem based learning approach described by Shoenfeld (1998) and Hmelo-Silver and Barrows (2006) as the "expert teacher" guides students as a facilitator in their learning rather than directing them exactly how their learning should take place.

There are levels of facilitation by the instructor for classrooms that use the PBL method. The process described by Jonassen (1997) for developing a PBL was used in the development of ill structured problems for this research study. According to Jonassen, the problem created for students must really exist in life. The design of five problem based learning questions were created for this study with the understanding from Jonassen that problems may appear to have an unknown answer, but in reality they actually do have a correct answer to the problem, or a hidden known. Secondly, the problems developed in this study were made according to Jonassen's understanding that the person who solved the problem determined the nature of the problem through multiple understandings and pathways leading to a solution. Using real world story problem developed by the instructor was a way of presenting and starting the PBL process to students (Barrows 1986, Hung 2006, Jonassen 2000, Laxman 2013, Williams et al. 2009).

Another piece of this study developed from Jonassen (1997) was that ill structured problems do have “constraints or requirements that must be accommodated” (Jonassen 1997). Constraints within this study completed at Dowagiac Middle School were task oriented. Students were to achieve the answer to the problem at hand using some sort of model or laboratory constraint. Students had freedom to design and develop their own experiments, but the overall outcome was suggested by the teacher in order to guide students to the correct pathway of learning. The teacher had constraints of how students showed the solution to their findings from the five different Problem Based Learning labs. This was achieved by using a teacher scaffolded inquiry method at first through the first three labs and then more student led inquiry for the final two labs. For the first three labs, the teacher guided students on how to accomplish their lab work, such as using specific lab equipment or requiring the measurements of mass or volume in their data collection. In labs four and five the students had more freedom to make additional developments to their learning by choosing if they needed to measure the mass, volume, weight, temperature, or any measurements they felt met their learning outcome and proved their answer to the provided question.

As previously stated, the history of Problem Based Learning was originally developed at the post-secondary level. The development of this research study in Dowagiac Middle School was also based on research findings from an introductory chemistry course at the University of Leicester, where students were grouped and given a series of real world scenarios and expected to plan, research, construct solutions to these problems (Williams et al. 2009). These students were required to do additional research on top of class lecture. This same process was used in Dowagiac where students needed to work collaboratively in researching content and processes that would help solve the given problems. This brainstorming and research session idea was achieved in Dowagiac Middle School as well by students filling out a “prelab” called a Problem Starter (Appendix A). The idea for the Problem Starter was developed from the “SET” sheet used in the University of Leicester. The basic layout of the “SET” sheet was designed for students to *summarize* the problem, show *existing* knowledge related to the problem, and to finally write down *things* to find out to solve the problem (Williams et al. 2009). This organizer idea was used to create a “prelab” worksheet for students at Dowagiac Middle School.

Problem Based Learning has been documented in depth through medical and undergraduate schools. The ideas of student collaboration, teacher directed and student led classrooms, documenting the scientific process through prelab worksheets, and lab based activities, can be applied to middle school science classrooms. According to findings of Janet Kolodner (2003), problem based learning can be used in the middle school classroom, but there are limitations in the learning of students of this cognitive age. This group’s research focused on a combination of three methods of project based learning, problem based learning, and case based reasoning to teach middle school students in order to give students real world experiences in their learning. Their attempt at using this method in middle school showed that “middle school students do not yet appreciate the need to make connections between what they know and what they are encountering” and “they are not good at having informed dialog, and do not know how to organize themselves to solve a problem.” The proper amount of scaffolding is necessary in middle school science classrooms in order to achieve a high level of learning by using problem based learning. For this reason, the students in Dowagiac Middle School were given a progression of scaffolding in terms of their writing prompts, brainstorming, communication, and research expectations. More facilitation from the teacher was necessary in the beginning of the five week unit at Dowagiac Middle School. From the findings of Kolodner, the teacher in this study used a highly teacher led inquiry approach for the first two labs before allowing students some freedom in their problem based learning processes.

Also in Kolodner's and colleages research, students were graphic organizer to develop specific areas of thinking, such as what were students thinking about, what was their plan, and to think about what their experimental design would look like when going through the lab activity. This experimental design was used as a guide for the prelab and lab worksheets in the study reported here. This gave students guidance and scaffold approach to what they should be doing while learning.

**Related Science Standards**

K-12 education in America has developed many versions of teaching standards and expectations in the last century in order to further student learning. Today, high schools and middle schools in Michigan are using the High School Content Expectations (HSCE) and Grade Level Content Expectations (GLCE) respectively. For the seventh grade science classroom in this research project, the GLCE have previously been used to guide and pace content for the year's curriculum standards. In anticipation of the Michigan Department of Education accepting and fully adopting the Next Generation Science Standards (The Next Generation Science Standards), the researcher and writer of this project assumed adoption in the near future and based all learning expectations on the NGSS for this seventh grade science class.

The Next Generation Science Standards drive teachers to use more engineering and inquiry approaches to learning in science classrooms. The GLCE also require teachers to use science inquiry processes much like the NGSS expects, such as "S.IP.E.1 Inquiry involves generating questions, conducting investigations, and developing solutions to problems through reasoning and observation." Another example of GLCE would be "S.IA.E.1 Inquiry includes an analysis and presentation of findings that lead to future questions, research, and investigations" (7th Grade Science Grade Level Content Expectations). Both of these standards push 7th grade students to use science processes to understand actual content expectations dealing with physical, chemical, and biological science in seventh grade.

Additionally the High School Content Expectations expect high school students to be scientifically literate. Being scientifically literate means that students can identify science principles, use science principles, use scientific inquiry, and reflect on social implications. Using scientific inquiry according to the HSCE means starting with "Observations, measurements, data using attribute-value descriptions at the beginning of the inquiry process. Then moving to finding patterns in data like laws, generalizations, graphs, and tables. Finally modeling theories using all of those learning points which is based on experiences first, then patterns, then explanations" (High School Content Expectations). This model of scientific inquiry was used as a guideline for the research study reported here.

The NGSS objectives used in this project are specifically directed towards the following: 1) MS-PS1-2 Analyze and interpret data on the properties of substances before and after the substances interact to determine if chemical reaction has occurred; 2) MS-PS-5 Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved; and 3) MS-PS1-6 Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes. Looking at the key words in these NGSS standards they are very similar with “analyze”, “interpret”, “develop”, and “design”, all common words with the GLCE for seventh grade. The content is mainly the same as well but looking closer at the NGSS, there is more emphasis on the three overarching ideas of Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas (The Next Generation Science Standards). A Problem Based Learning classroom utilizes these three ideas. Learning objectives from the NGSS and GLCE in this study of Problem Based Learning are shown in Table 1.

Table 1 Content Objectives

| Grade Level Content Expectations | Next Generation Science Standards |
|---|---|
| **P.CM.M.2** Chemical Changes- Chemical changes occur when two elements and/or compounds react (including decomposing) to produce new substances. These new substances have different physical and chemical properties than the original elements and/or compounds. During the chemical change, the number and kind of atoms in the reactants are the same as the number and kind of atoms in the products. Mass is conserved during chemical changes. The mass of the reactants is the same as the mass of the products<br>**P.CM.07.21** Identify evidence of chemical change through color, gas formation, solid formation, and temperature change<br>**P.PM.07.24** Describe examples of physical and chemical properties of elements and compounds (boiling point, density, color, conductivity, reactivity). | **S.IP.E.1** Inquiry involves generating questions, conducting investigations, and developing solutions to problems through reasoning and observation<br>**S.IA.E.1** Inquiry includes an analysis and presentation of findings that lead to future questions, research, and investigations<br>**MS-PS1-2** Analyze and interpret data on the properties of substances before and after the substances interact to determine if chemical reaction has occurred<br>**MS-PS-5** Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved<br>**MS-PS1-6** Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes |

Table 1 shows content objectives for both the Grade Level Content Expectations and also the Next Generation Science Standards for 7$^{th}$ grade science were used in this study.

When the researcher began reflecting on the many methods of teaching it became evident to look further into the methods of Problem Based Learning and how it can be used to teach the 3 pillars of NGSS. The number one incentive to using PBL was to increase the interest level of the students so that they can gain a deeper understanding of the material. Based on previous teacher experiences in middle school, the researcher considered student engagement one of the most beneficial ways of increasing depth of knowledge. Using Problem Based Learning as the structure behind teaching curriculum, middle schools students should be able to connect the learning objectives to their everyday experiences and have the motivation to learn because of their higher level of engagement due to the personal connection to the material.

**Class Descriptions and Demographics**

The study was administered at Dowagiac Middle School located in the district of Dowagiac Union Schools in Dowagiac, Michigan. Dowagiac Union School district encompasses 170 square miles in southwestern Michigan. Dowagiac Middle School has approximately 506 students in a $6^{th}$ through $8^{th}$ grade building, averaging approximately 28 students per science classroom. Dowagiac Middle school is supported by Title 1 funding on a yearly basis. Approximately 73% of the student body qualifies for free or reduced lunch. Parent/teacher conferences are attended by 44.3% of the parents. Dowagiac Union Schools participates in a Migrant School Summer Program and also an Alternative Education Program during the school year (Dowagiac Union Schools Annual Report 2013-2014).

**Science Overview**

The main science concepts within this study all related to chemical reactions, physical and chemical properties/changes of matter. At the time of this unit, the classes in this study were already taught basic particle movement and arrangement to explain Solids, Liquids, Gases, and Plasma. The students had previous knowledge of the effect on molecules of temperature changes and were able to draw a phase change diagram of water. The basic science to be learned by students is outlined below.

During a chemical reaction reactants combine to form products. In a chemical reaction, the total number of atoms does not change, and mass is conserved. In order to increase the number of atoms in the product, the number of atoms on the reactant side of an equation must also increase.

During a chemical reaction reactants combine to form products. In a chemical reaction, the total number of atoms does not change, and mass is conserved. One of the problems presented to students in this unit was how the chemistry of an air bag helps inflate an airbag quickly enough to save a life in a car. Air bags use a chemical reaction of sodium azide which rapidly decomposes to sodium and nitrogen gas. This reaction takes place in 1/25$^{th}$ of a second. Other reactions occur in the air bag as well to ensure the highly reactive sodium metal is no longer dangerous if the airbag deflates during the collision ($2\ NaN_3 \dashrightarrow 2\ Na + 3\ N_2$) (Merola, 1999)

The students in this study did not use sodium azide reactions, but rather a safer reaction that uses the household kitchen items of baking soda and vinegar. The reaction of sodium bicarbonate and acetic acid produces sodium acetate and carbonic acid. The carbonic acid then quickly decomposes into water and carbon dioxide.  The gas produced in the students' lab was carbon dioxide gas to inflate their "air bags."

Chemical reactions can be either exothermic or be endothermic.  A general rule to follow in chemical reactions:  it takes energy to break chemical bonds, and energy is released when bonds form.  In the exothermic reaction of calcium chloride and sodium bicarbonate, these two substances break their bonds which required energy.  More energy is released when the new bonds in the products are formed, so the temperature increases and you feel heat from the reaction.  In the acetic acid and sodium bicarbonate reaction, energy was required to break these substances, but when new bonds formed in the products, not as much energy was released when the new bonds form, making it an endothermic reaction and it feels cool to touch.

## Implementation

In the summer of 2014, previous to implementing this unit, the teacher spent five weeks researching and designing a unit that fully utilized problem based learning for the middle school $7^{th}$ grade science classes at Dowagiac Middle School. The teacher researched the history of problem based learning used in medical school, colleges, and secondary schools. The teacher developed a unit containing five ill structured real life problems for chemical and physical changes, which utilized a student led problem-based learning style. The teacher researched laboratory activities that would demonstrate real life interest for seventh grade students and tested these laboratory activities to collect knowledge of how these activities would carry out in classes for students. The teacher also developed a standard laboratory write- up format based on research based ideas from other studies (Appendix A).

The Problem Starter (Appendix A) was developed prior to the beginning of the unit and was used as the main source of data collection outside of pre and post test data. The Problem Starter was developed to be a graphic organizer for students to record their process of science This organizer was developed by the teacher at Michigan State University in the summer prior to implementation and was done so to see progress of students' understanding of how the scientific process.

At the start of this study, before any teaching of the unit began, consent forms were given to students (Appendix B). These consent forms were handed out to students to be read with their guardian at home. The consent form was an agreement on being part of the study. Consent forms were handed into a drop cardboard box that was taped shut so the teacher was unable to read any of the consent forms or know the number of students consenting to be in the study because students turned in their consent forms before the unit began.

Before the unit was started a survey was given to students before any of the five PBL process had begun. The survey was given on computers where students had to read 17 questions on the Survey Monkey® website (Appendix C). Students had to type in the link into a web browser and type in their own name before beginning the survey. The survey was given to students to see a baseline of what their own opinions were about science. Survey questions asked if students liked science, if it is difficult for them, and how they feel about working in groups. The same survey was also given to students after the unit to see a comparison about their thoughts on how they have grown as students over the five week unit.

A pretest of 25 questions and three writing response questions (Appendix D) was given to all four classes in the study to determine the initial level of knowledge on chemical and physical properties as well as the difference between chemical and physical change. The results were analyzed as a baseline to compare against at the end of the unit. The same test was given as a posttest after 5 weeks of implementation of PBL. Many students finished the pretest within 15 minutes with less than 10 taking the entire 45 minute class period to finish the pretest (Appendix D). A general outline of the unit can be followed below in Table 2.

Table 2 Sequence of Events

| Timeline | Event(s) | Content Objectives |
|---|---|---|
| Day 1-25 | Problem Based Learning Process<br>Problem Starter<br>Lab Activities | S.IP.E.1<br>S.IA.E.1<br>MS-PS1-6 |
| Day 1 | Survey<br>Pretest | |
| Day 2 | Story Problem 1 *Dissolving Sugar*<br>Problem Starter<br>Research<br>Prelab and Lab<br>Conclusions/Discussion | P.PM.07.24<br>MS-PS1-2 |
| Day 5 | Story Problem 2 Mixtures<br>Problem Starter<br>Research<br>Prelab and Lab<br>Conclusions/Discussion | P.PM.07.24<br>MS-PS1-2 |
| Day 10 | Story Problem 3 Melting Wax<br>Problem Starter<br>Research<br>Prelab and Lab<br>Conclusions/Discussion | P.CM.07.21<br>MS-PS1-2 |
| Day 15 | Paper Clip Activity<br>Story Problem 4 Unclogging Drains<br>Problem Starter<br>Research<br>Prelab and Lab<br>Conclusions/Discussion | P.CM.07.22<br>P.CM.M.2<br>MS-PS1-2<br>MS-PS-5 |
| Day 20 | Story Problem 5 Air Bags<br>Problem Starter<br>Research<br>Prelab and Lab<br>Conclusions/Discussion | P.CM.07.22<br>P.CM.M.2<br>MS-PS-5 |
| Day 21 | Posttest<br>Survey | |

Table 2 shows the sequence of events over the course of the teaching unit on Problem Based Learning from Day 1 to Day 21. The sequence of events shows the title of each PBL Lab and the process of learning of the labs, as well as learning content objectives.

The unit consisted of five PBL labs (Appendices E, F, G, H, and I) which were student centered and each lab consisted of the same lab write up template. The write up layout contained an initial Problem Starter experimental design, data collection, and discussion. This lab sheet was referenced to the students as the "Problem Starter." The Problem Starter (Appendix A) will be discussed in detail. Each Problem Starter consists of nine major topics: Existing Knowledge, Learning Issues, Course of Action, Hypothesis Development, Testing Idea, Variables, Diagrams, Description of Procedure, and What's Next? categories. The first three categories of the Problem Starter were worked on by students prior to any lab work. The Problem Starters were assessed based on measures of zero, one, and two using two rubrics (Appendix J and K).

The first three sections of the Problem Starter were completed by students in collaborative groups for labs 1, 2, 3. Lab 4 and 5 Problem Starters were completed by individuals on their own in order to assess that their work was credited to their own knowledge of the scientific process rather than a dependence on the group or others. For each lab the Problem Starter was handed out to the students and a story problem was read aloud to the class while showing the problem on the projector. Thus, each student saw and reread the problem. The students were required to unpack the story and first summarize the problem or provide any explanations of science concepts from their preexisting knowledge. Students were also expected to develop a solution to the problem before any research could take place.

The second portion of the Problem Starter was to develop questions about the problem, or questions that could help solve this problem. The third section of the Problem Starter was to find research on the topics in the story problem that could benefit the students in solving the problem.  For the research portion of the Problem Starter students had access to their textbooks, cell phones, Google Chrome Books®, and any resource materials at the school and local library.  The main resource students used were the Google Chrome Books® and Google® while searching information on their own, or suggested websites from the teacher. The purpose of student research was to guide the students into thinking about a hypothesis to test and also to outline their investigation.  Students were expected to understand basic content from their research that would instill curiosity about the PBL and build a thoughtful hypothesis.  After the lab was completed, formal lecture, discussion, and notes were provided to fill in the gaps of student ideas while working in the laboratory.

After research, the students formulated hypothesis statements.  These statements were to be made using reasoning in their statement.  Students were expected to make a statement using the following words, "I think _____ because" or "If I do this, and then this will happen _____ because."  In PBL 1 *Dissolving Sugar* (Appendix E) the formal hypothesis statement requirement was not suggested to students.  This was In order to gauge students' initial abilities to write a hypothesis.  From here direct instruction was done in order to increase student knowledge of a more formal scientific process rather than a "guess and see what happens next."

As students formulated hypothesis statements, student testing ideas erupted in the form of group discussion and side conversations with many students around the room and with the teacher.  This portion of the PBL was probably the most difficult portion for students initially because of student centered model used in this study.   In order for students to formulate a strong hypothesis, they often needed to know what they were testing, how they were going to test it, and an understanding of variables and the control. Formulating a step by step procedure often seemed to be the most daunting task for all classes in the first PBL 1 *Dissolving Sugar* (Appendix E). Again, not much support from the teacher was given in PBL 1 in order to set a baseline of knowledge of the scientific process for the study. After the first PBL 1 direct instruction was given on controls in an experiment, as well as dependent, and independent variables. Direct instruction was also given on how to properly design a step by step procedure.

Students were given a warm-up in class to explain the step by step procedure for making a peanut and butter jelly sandwich. This was used for students to work towards giving a strong, detailed step by step procedure. Student sample procedures were read aloud by the teacher and students were able to figure out the positives and negatives in these student generated procedures. Students were able to understand when a procedure was missing key information, contained gaps, or how something can be interpreted incorrectly based on how it is written. Students were also able to understand procedures that were clear and precise, with clear details that would allow anyone who read the instructions to begin making exactly what was described by the procedure.

The Problem Starter was designed by the teacher with a section for students to draw their experiment on paper so they could physically see what they were going to do. Again, no suggestions were made by the teacher on how to draw out experiments in PBL 1. Students were directed to draw what they were going to be doing in the laboratory. The purpose of this section of the Problem Starter was to allow students a brainstorming session of ideas through discussion and visually draw their laboratory testing setup. This allowed them to see holes or gaps in their written out procedure and not miss any steps. No teacher instruction was given explaining how to correctly draw out their experiments with each PBL until after the first PBL. Direct instruction was given to students on suggestions for drawing materials in their process, along with either arrows showing each step, or numbering the steps as they made their drawings.

Once students were testing their *designs, observations and data tables* were created by students. The teacher needed to remind students often throughout the unit to keep on taking careful observations and recording their subjective data under *observations,* while recording their objective data within organized tables. Data tables in this unit were created directly on the Problem Starter lab sheet, but for labs 4 and 5 data tables were provided by the teacher for students to record information in a premade Microsoft Excel® file. The Excel® files were designed to give instant graphs to students once they placed data into the correct columns and rows. Direct instruction after PBL 1 (Appendix E) was necessary for creating a detailed data table. Students tended to write down random numerical findings in this Data Table box, so teacher input was necessary on how to build a table that accurately displayed their findings.

The final portion of the Problem Starter was the *What's Next?* category. This category allowed students to think about what they had accomplished through the PBL process. Two questions were asked. The first was "what modifications can you now make from what you learned?" The second question asked was "what new questions have you come up with since experimenting?" These two questions were asked with every PBL. The intent of these questions was to have students identify how they could go back to their research, back to their hypothesis, back to their experimental design, back to data collection, back to the process of observations, and change what they did in the investigation and make changes. The purpose of this was to show students that the scientific process is not a linear step by step process but rather a cyclical or systematic approach of going back and forth at any point in the investigation to make changes to study a topic more in depth. The purpose of the second question was to challenge students to think about what else they could test or investigate related to their study, forcing them to think back in the cycle of their learning and brainstorm and start the entire science process over again, or from any point the process.

**Description of Lab Activities**

1) *Dissolving Sugar* (Appendix E). The story or problem presented to the students was about two brothers who were not able to make Kool-Aid® correctly with enough sugar in it. The learning objective in this lab focused on physical properties of matter and for students to be able to describe the process of dissolving and to see the limits as to how much sugar can dissolve in water. The students investigated what happened to the amount of dissolved sugar when changing the temperature or the amount of water. Students recorded the mass of sugar dissolved into their samples, as well as the volume of water used. For a few groups temperature was recorded as well if they were using temperature as a variable in their investigation. All of the groups developed their own experimental design and used materials such as water, Spartan® granulated sugar, Pyrex® beakers, metal stir sticks, Pyrex® graduated cylinders, Ohaus® triple beam balances, plastic weight trays, and plastic measuring spoons.

2) *Mixtures* (Appendix F). The story or problem presented to the students was about a family moving to a new home, but while moving a box of kitchen supplies spilled in the driveway which contained many household items like sugar, popcorn, poppy seeds, iron pills.

During the process some of the dirt from the driveway mixed into the sample. The family wanted to save what they could so separating this mixture was the basis of the problem. The students investigated how to separate mixtures by physical means. The learning objective focused on physical properties of matter such as dissolving, size, shape, magnetic properties, color, and density. The goal for students was to separate the mixture into five weight trays and record the final mass of each substance. All of the groups developed their own experimental design and used materials such as magnets, water, Pyrex® beakers, Spartan® coffee filters, tweezers, plastic spoons, Pyrex® graduated cylinders, weight trays, Ohaus® triple beam balances, and measuring spoons.

3) *Melting Point* (Appendix G). The story or problem presented to the students was about a daughter who was asking her mother about the candles burning in their home. She was curious about how it was made to have the wick inside of a solid. The learning objective in this lab concentrated on the physical properties of melting and freezing points of matter. The students investigated these properties by taking paraffin wax through phase changes from a solid to a liquid and back into a solid form. All groups created their own experimental design and used materials such as paraffin wax, Pyrex® beakers, test tubes, water, Pyrex® graduated cylinders, Ohaus® triple beam balances, plastic weight trays, stir sticks, thermometers and hot plates.

4) *Unclogging Drains* (Appendix H). The story or problem presented to the students was about two siblings who were trying to unclog a drain in the bathroom of their home. One of the siblings knew to unclog the drain with a natural ingredient that is not harmful to the

environment. The learning objectives in this PBL was to introduce chemical properties and chemical changes. Students were to explain how a chemical reaction takes place and explain the evidence for knowing a chemical reaction has taken place. Another learning objective that students investigated was the cause and effect relationship between products and reactants related to the concentrations of ingredients within reactions. This lab was developed to have students solve this problem after they researched the correct cleaning supplies for this activity. The teacher suggested to the students that baking soda and vinegar would be used in their chemical reaction. The students investigated the effects of baking soda and vinegar concentration and what that would do to the overall reaction. A goal was given by the teacher to have a reaction cause gas production halfway up a graduated cylinder and also to have gas production up the entire cylinder but not to overflow. Students were to use a systematic approach at figuring out their concentrations (measured in mass for baking soda and volume for vinegar) of the reactants to make the gas production to a specific height. Students were responsible for determining their control, independent variable, and dependent variable all on their own with no teacher support. All groups used Pyrex® graduated cylinders, Spartan® baking soda, Spartan® vinegar, soap, plastic weight trays, Ohaus® triple beam balances, and rulers.

5) *Air Bags* (Appendix I). This was a two part story problem, scaffolding learning between two situations. The first story problem was a car that crashed into a telephone pole in Dowagiac (town of the students) and the air bag of the car did not work properly. The first research topic was to determine how air bags work and inflate. The second story explained that the malfunction in the air bag was caused by a mistake in the chemistry within the car

airbag. The students researched and constructed new airbag designs that would withstand the pressure from a crash. Students were told by the teacher to use chemicals of baking soda and vinegar that they had previously used. Prior to their Problem Starter (Appendix A) being completed, the teacher showed students the laboratory testing setup of a ramp and a toy car. The car was rolled down ramp, and the airbag on the front of the car was inflated to keep the car from making contact with the wall. The learning objective in this investigation was related to lab 4 because students used the same reactants, but they needed to show that mass was conserved in their reactions. The materials students used in this lab were Spartan® baking soda, Spartan® vinegar, plastic bags, plastic weight trays, Ohaus® triple beam balances, Pyrex® graduated cylinders and the toy car.

Middle school is when students are taught chemical and physical changes as well as chemical equations and reactions. Students in middle school learn about atoms and elements in 7$^{th}$ grade. (GLCE, NGSS) Students at this age find it hard to visualize what an atom looks like, and how to model them. The goal of the Paper Clip activity (Appendix M) was for students to be able to model what they are learning. Representing atoms as colored paperclips was used as a teaching point in between PBL 4 and PBL 5. Each paper clip represented one individual atom according to color. Green paperclips were used to represent carbon, blue paperclips were used for oxygen, red paperclips were used for hydrogen, and yellow paperclips were used for sodium. Students were responsible first for color coding their atoms and then looking closer at the reaction between baking soda and vinegar. Then students identified the total number of each atom on the reactant side of an equation, and then identified the total number of each atom on the product side of the reaction. The next step was for students to lay out the correct number of paperclips on each side of the equation. From here students modeled baking soda atoms with the paperclips and modeled vinegar (acetic acid) looked like using paperclips. Students then needed to set up their product side of the reaction with their paperclips.

Direct teacher instruction between each PBL was very beneficial in increasing details on the student writing samples. After the first PBL the teacher developed a PowerPoint® showing student writing samples that were labeled "Pretty Good" and "Not So Good." The writing samples were actual student writings that the teacher typed up and no names were used to keep the sample anonymous. Students saw well thought out research, hypotheses, and procedures. Students saw the opposite of these well thought out writing samples that were not so good and relate to them. Students learned from their own mistakes and see how to improve their own writing responses when writing out their Problem Starters (Appendix A).

Finishing up the progression of this study was a final posttest. The post test (Appendix D) was the same as the pretest. Using the same posttest allowed for a comparison using a paired T TEST between the beginning and the end of the unit. After students' tests were scored and returned to them to see their grades, students answered the same Survey Monkey® (Appendix C) as they did before the study began. This survey was used to see any changes in the mindset of students in science class in the 5 weeks period of this study.

# Results

The purpose of this researched based thesis was to demonstrate how teaching using a student centered problem based learning approach would benefit students. Additionally learning the scientific process was expected to improve their abilities to problem solve and be able to show an increase in their ability to use the scientific process in their learning.

For each lab report, grading rubrics (Appendices J and K) were used to identify strengths and weaknesses in the student's writing samples. One rubric (Appendix J) was used starting with the first page of each lab report that students worked on for each PBL lab. This page was completed before any laboratory work and completed as a brainstorming sheet for the students to begin their problem based learning. The Problem Starter (Appendix A) was assessed and analyzed with a 0, 1, 2 grading system with zero being the low score and two being a high score. Grading each student's writing sample this way allowed the teacher to be able to statistically analyze initial thought processes and brainstorming patterns in growth over the course of each lab report, and each PBL process.

Another rubric (Appendix K) used was designed to assess student learning and growth of the scientific process through each lab. Each parameter of the scientific process was assessed on the same scale of 0, 1, 2 with zero being a low score and two being a high score. Each category was designed to be a major point of interest in their development of learning the scientific process and was individually graded independent of every other category. The flow of the lab sheet was designed to follow a traditional scientific process approach with forming a hypothesis first, followed by designing the experiment, testing the experiment, observing and recording any information from their experiment, and finally analyzing what happened in the experiment (Appendix K). Grading each student writing sample in this way allowed the teacher to be able to statistically analyze patterns in growth over the course of each category in each lab report from PBL 1 to PBL 5.

Another rubric (Appendix L) was used for a section of the pretest and posttest assessment (Appendix D) that contained three essay questions and awarded students points for each question. The three essay questions were each valued at three points towards the final raw test score which was out of 34 total points. The essay portion of the pre and posttest had a total value of 9 points.

**Lab Report Analysis**

Each parameter of the Problem Starter (Appendix A) was scored as a “0”, “1”, or a “2” based on a grading rubric (Appendix J and K). The average score of each parameter was calculated for the seventy-five students using Microsoft Excel ®. Figure 1 shows averages for each parameter for the five labs.

Figure 1 Average Score vs. Problem Starter Parameters for PBL 1,2,3,4,5

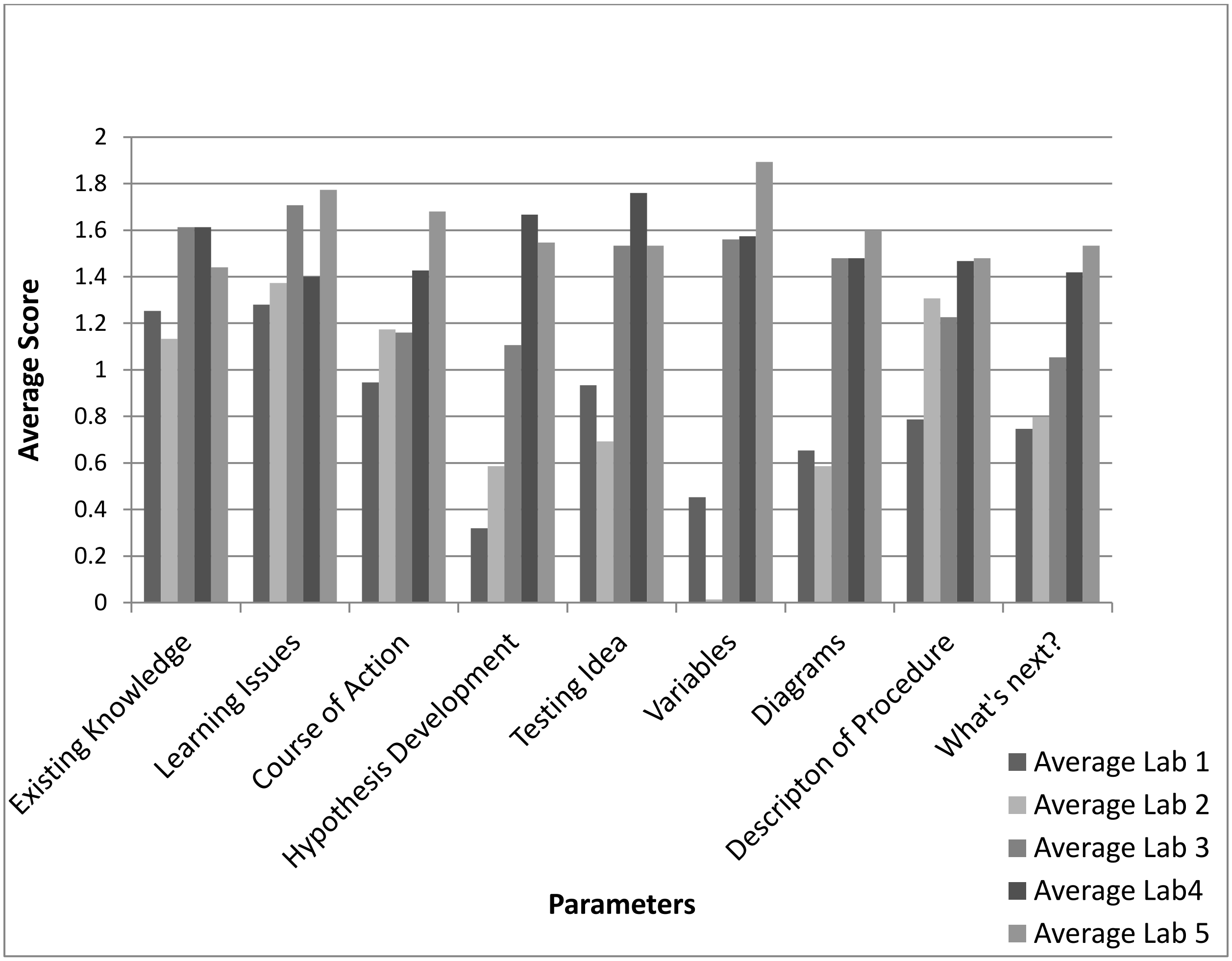


Figure 1 shows the Average Score vs. Problem Starter Parameters for PBL 1 through PBL 5. Each of the parameter names are on the x axis. The y axis shows the average score on the Problem Starter. These scores were based on a 0, 1, 2 grading scale with 0 being the low score and 2 being the high score. n=75 Students

Each Problem Starter (Appendix A) lab report was also analyzed using a paired t test through using the Microsoft Excel® TTEST function Table 3 shows all of the lab comparison p values for each of the parameters. The first PBL Problem Starter for *Dissolving Sugar* (Appendix E) was used as a control in comparing data from each lab to one another. Thus, each PBL Problem Starter was then compared to this lab as a control with a paired t test. PBL Lab 1 *Dissolving Sugar* (Appendix E) was compared to Lab 2 *Mixtures* (Appendix F). PBL Lab 1 *Dissolving Sugar* (Appendix E) was compared to Lab 3 *Melting Wax* (Appendix G). PBL Lab 1 *Dissolving Sugar* (Appendix E) was compared to Lab 4 *Stinky Drains* (Appendix H). Finally, PBL Lab 1 *Dissolving Sugar* (Appendix E) was compared to Lab 5 *Air Bags* (Appendix I). Data were also compared from the raw grading score for each major parameter for each PBL lab 1 through 5. The raw score for the parameter averages was from the grading rubric based on the numbers 0, 1, 2 which a zero being a low score and a 2 being a high score (Table 3).

Table 3 Lab Comparison P Values

| (p <.05 significant to accept alternative hypothesis) | | | | |
|---|---|---|---|---|
| Parameter | 1 vs 2 | 1 vs 3 | 1 vs 4 | 1vs 5 |
| Existing Knowledge | **.08** | 1.17E-05 | 1.17E-05 | .006 |
| Learning Issues | **.14** | 6.43E-07 | **.12** | 4.27E-07 |
| Course of Action | .01 | .01 | 9.52E-08 | 2.66E-11 |
| Hypothesis Development | .002 | 4.54E-12 | 1.65E-27 | 1.98E-24 |
| Testing Ideas | .0004 | 7.64E-10 | 1.0E-17 | 1.67E-10 |
| Variables | 1.73E-10 | 2.39E-19 | 3.43E-18 | 4.33E-34 |
| Diagrams | **.2** | 5.56E-12 | 3.02E-12 | 1.22E-14 |
| Description of Procedure | 1.3E-09 | 3.5E-07 | 8.74E-15 | 1.21E-12 |
| What's Next? | **.24** | .001 | 1.54E-08 | 5.03E-13 |

Table 3 shows the p values from a series of paired T TESTS, using PBL Lab 1 as the control. Column 1 vs 2 shows PBL Lab 1 vs PBL Lab 2 p values. Column 1 vs 3 shows PBL Lab 1 vs PBL Lab 3 p values. Column 1 vs 4 shows PBL Lab 1 vs PBL Lab 4 p values. Column 1 vs 5 shows PBL Lab 1 vs PBL Lab 5 p values. P values in bold are the values not significant. n=75 students

The PBL labs were analyzed in detail based on nine major parameters. Each parameter was individually assessed and compared to the control lab PBL 1. Using Microsoft Excel® total of nine paired t tests were calculated when analyzing scores from PBL 1 to PBL 2, one for each of the parameters. This same calculation was done for each of the 9 parameters when comparing PBL 1 to 3, PBL 1 to 4, and PBL 1 to 5.

When comparing all of the PBL labs, the following null and alternative hypotheses were used: The alternative hypothesis of this study for PBL labs states "There is a difference in student scores when using problem based learning to teach the scientific process." The null hypothesis of this study was "there is no difference in student test scores by using problem based learning to teach the scientific process." Using PBL 1 as the control and base raw scores for knowledge on the scientific process made it possible to use a paired t test for all other PBL labs after teaching had taken place on how to work through the problem based learning method.

When comparing Lab 1 *Dissolving Sugar* (Appendix E) to Lab 2 *Mixtures* (Appendix F), five of the nine measured parameters were significant based by different ($p < .05$). Overall there was no significance in *Existing Knowledge, Learning Issues, Diagrams, and the What's Next category*. It is safe to assume that there were no significant improvements from lab 1 to lab 2 in these three areas. All other parameters students showed a significant difference in their scores. For the Learning Issues, from Lab 1 to Lab 2, students did not show significant growth in the quality of questions they needed to ask themselves in order to fully understand how to solve the story problem. For the Diagrams parameter in Lab 2 students were unable to show growth in the detail of diagraming out their experiments. This could have been because students were still not visualizing ahead of time what their lab would look like in physical form on their lab stations. Students struggled with writing the pre lab procedure for the first two labs and these data show that they did not fully visualize what they needed to accomplish in the lab. For the *What's Next?* Parameter, students did not show a significant growth in their post lab writings. Students from lab 1 to lab 2 were not able to fully embrace the PBL concept of completing the entire PBL problem finishing with a quality question that could lead them into an entirely new investigation. Students may have been satisfied with what they had accomplished and did not fully engage in finishing their writing for the second PBL. It is safe to accept the alternative hypothesis on five of the nine parameters from Lab 1 to Lab 2.

When comparing Lab 1 *Dissolving* to Lab 3 *Melting Wax*, students were able to show significant growth in all of the nine parameters. (Table 3) For the third lab, the teacher gave enough instruction before the prelab about the fundamentals of problem based learning in a classroom. A PowerPoint® was used before the *Melting Wax* Lab that included writing samples from students in the prior 2 labs. Writing samples were clearly labeled "Pretty Good" and "Not So Good." Students were shown writing samples from actual student work on the projector screen in front of class, where all names were stripped and writings were typed. Students were able to see from these samples what were quality responses for all of the nine parameters, and what were not good responses for each of the nine parameters. This provided a huge benefit to the writing in Lab 3 *Melting Wax* because all parameters showed significance in improvement. It is safe to accept the alternative hypothesis for all parameters when comparing

Lab 1 and Lab 3 and assume that problem based learning does help students learn the scientific process.

When comparing Lab 1 *Dissolving* to Lab 4 *Stinky Drains* (Appendix H), eight of the nine parameters showed a significant p value score of $< .05$. It is safe to accept the alternative hypothesis on all of the parameters except for the *Learning Issues* when comparing these two labs. The *learning Issues* parameter again, is the parameter where students were required to write their own questions based on what they already know, and what they need to ask in order to solve the problem, or what they need to ask in order to research quality information. For the fourth PBL lab, students were expected to depend less on their group for their prelab and more on their own ideas and thoughts for the Problem Starter (Appendix A). Students were allowed to work in the lab together on Lab 4, but were expected to work independently on their own for the Problem Starter. This was done to force the student led model, where individual thinking needed to take place in order to fully engage themselves in the process of what they were trying to accomplish. The teacher allowed students to talk to one another for the entire pre lab except for the first three parameters, *Existing Knowledge, Learning Issues, and Course of Action*. It is important to note that these three parameters are the first three parameters on each PBL process. In Lab 1, 2, and 3 students worked in groups on these three parameters while in Lab 4, students worked independently on the Problem Starter with no assistance. The results are encouraging because in two of the three categories students showed a significant growth from Lab 1 to Lab 4. During class periods the *Learning Issues* parameter was often the most difficult part of the Problem Starter for students to handle and many students asked the teacher for help on this section. Many students sought help, wanting to know how to ask a good question. The issue of quality vs. quantity came into play with these 7th grade students. Many of them were able to produce a quantity of questions for this parameter, but often the quality of these was inferior. The final PBL Lab 5 *Airbags* was also compared to Lab 1 *Dissolving Sugar* (Appendix E). All nine parameters of interest statistically showed $p < .05$. It is safe to accept the alternative hypothesis that Problem Based Learning did have positive influence students in learning of the scientific process.

**Student Quotes**

Using the rubric (Appendices J and K) as a guide for evaluating student writing samples, the teacher was able to categorize writing samples into the 0, 1, 2 categories. Some of the students who previously had quality writing skills were able to achieve a score of 1 or 2 without any guidance from the science teacher. Students who lacked these skills struggled at first with the Problem Starter (Appendix A). Some of the students were shocked at the expectation of how much there was to write in this Problem Based Learning unit.

Students showed the least amount of growth from PBL Lab 1 to PBL Lab 2. The "*Learning Issues"* portion of the Problem Starter (Appendix A) was developed to get students to think of quality questions that would help them further investigate their problem. This part of the Problem Starter, in the opinion of the teacher, was one of the most important sections of the student writings. The "Learning Issues" showed the teacher whether or not students were on track in their process of learning the science content. The following writing samples are from students in the first and second lab where minimal guidance was given from the teacher and questions scoring a 2 from the rubric developed from PBL lab 1 where students were expected to figure out how much sugar could dissolve in water: "What does solubility have to do with the Kool-Aid? How much water is in it? How much sugar do they have?" (Student 48) "If you got rid of some water would it taste better?" (Student 13) These students were asking questions about the process of how sugar actually dissolved in the water.

The following is an example of a student from PBL Lab 1 that was scored as a 0 from the Problem Starter (Appendix A): "Would he need that much Kool-Aid. How much water would. How much the water can hold." (Student 4) This writing sample does not show thoughtfully generated questions compared to the students who were asking questions that could further their investigations.

Another parameter of the Problem Starter (Appendix A) that did not show significant growth from PBL 1 to PBL 2 was the "*What's Next?"* category. This was considered by the teacher to be a valuable point of interest because it showed if the student was thinking beyond the investigation and considering further variables to test in another investigation. The purpose of this section was to show that students were thoughtfully considering what they could test and investigate next. The teacher was looking for modifications to the lab setup that students had designed themselves and was expecting that they would see their mistakes and learn from them. Also the teacher was expecting that students would develop new hypothesis based on their findings in the lab they just completed. An example of a quality answer for this section was: "Does Sugar and Kool-Aid dissolve in water no matter what the temperature?" (Student 9) This student was looking to change a variable in the process instead of just changing the amount of sugar or water as many students suggested in this section.

The teacher in this study was looking to see progress in hypothesis development from the first lab to the fifth. Table 4 shows a series of student quotes from the first lab to the last and these samples were chosen as good examples of either a “0” or “2” scores (Appendix K). Students were taught after the second PBL to use the format of “I think _____ because” or “If I do this, and then this will happen _____ because.”

Another parameter the teacher in this study was looking to see progress was in procedure development from the first lab to the fifth. Table 5 shows two writing samples. The first writing sample is a procedure score of “1” from student 11 and the second scoring a “2” from student 3. These samples were chosen to reflect a good example of what a score of “1” and “2” based on the grading rubric (Appendix K).

Table 4 Hypothesis Progression from PBL Lab 1 to PBL Lab 5

| PBL Lab | Hypothesis Score of "0" | Hypothesis Score of "2" |
|---|---|---|
| 1 | I predict that we are going to put sugar in water by adding scoop by scoop. (Student 4) | No students earned a score of 2 |
| 2 | I think if we use our procedure we will be able to separate the ingredients (Student 7) | If we use a magnet the iron pills will come out and we could take out the popcorn kernels, and put the rest in water poppy seeds float, sand sinks and sugar dissolves." (Student 13) |
| 3 | I think that the Parrafin will melt in less than 20 minutes. (Student 99) | If I heat the wax then the wax will melt because the video said that it melts at 25 degrees Celsius. (Student 67) |
| 4 | The drain will become useful again (Student 62) | I think that the baking soda and vinegar are going to work together and unclog the drain with the soaps help to contain the overflow over the drain because the baking soda and vinegar together will create carbon dioxide and dissolve the object in the drain. (Student 9) |
| 5 | I think it will weight one gram (Student 62) | I think that if you add 9mL and 4g of baking soda that the bag/air bag will expand because that is how the vinegar and baking soda and vinegar work together. (Student 9) |

Table 4 shows the Hypothesis Progression from PBL Lab 1 to PBL Lab 5. The column on the left shows the PBL lab number. A scale score of 0, 1, and 2 were used to score the Problem Starter parameters with 0 being the low score and 2 being a high score. The column in the middle shows examples of student hypothesis scored a 0 on the scale. The column in the middle shows examples of student hypothesis scored a 2 on the scale.

Table 5 Procedure Progression from PBL Lab 1 to PBL Lab 5

| Procedure Score of "1"<br>PBL Lab 1 | Procedure Score of "2"<br>PBL Lab 2 |
|---|---|
| 1. Find out how much water will be in the beaker<br>2. Use hot plate to heat up the water<br>3. Measure sugar<br>4. Write data<br>5. Try again<br>(Student 11) | 1. We will need a bag, baking soda, vinegar, and graduated cylinder, triple beam balance, metal spoon<br>2. Measure 4g baking soda on triple beam balance.<br>3. Put the baking soda in one side of the bag.<br>4. Measure vinegar with triple beam balance<br>5. Put the vinegar in the bag and quickly close it so it will explode.<br>6. Measure the bag with the triple beam balance<br>7. Make the car crash into the air bag and see if inflated<br>8. Measure the bag again to see if it stayed the same<br>9. Repeat this process until we succeed with different measurements<br>(Student 3) |

Table 5 shows the Procedure Progression from PBL Lab 1 to PBL Lab 5. A scale score of 0, 1, and 2 were used to score the Problem Starter parameters with 0 being the low score and 2 being a high score. The column on the left shows a score of "1" from PBL 1 and the column on the right shows a score of "2" from PBL 5.

**Pre and Posttest Differences**

The pre and posttest (Appendix D) had a maximum score of 34 points (25 points from multiple choice and 9 from essay). The pretest was given before any content or any student lead PBL has occurred. Once all five PBL labs were completed, a post test was given to students. To analyze the data from the pretest to the post test, a paired t test was used to show any significance in the data. The Microsoft Excel® TTEST function was used to analyze raw scores from students. Data from the pretest and posttest were also analyzed by comparing the raw average score of the entire student sample to the post test raw average score for the entire student sample.

The formal hypothesis of this study was "There is a difference in student scores when using problem based learning to teach the scientific process." Pretest data show an average raw score of 12.52 out of a maximum of 34 possible points. This raw score is equivalent to a percentage of 36.83% on the pretest. The posttest average raw score for the student population was 26.63, equivalent to a percentage of 78.32%. The increase in raw score of 14.11 points (51.69 % points increase) is statistically significant based on a paired T TEST of seventy five students.

Using a Problem Based Learning approach showed a significant difference in student learning based on the pre and post test scores (paired T TEST of 1.52x10-35). It is safe to accept the alternative hypothesis and reject the null hypothesis based on a 95 % confidence interval. Therefore, with a P value of <.05, the alternative hypothesis can be accepted. It is acceptable to assume the Problem Based Learning approach influenced the learning of the scientific process for the student population.

**Subjective Assessments**

The teacher in this study subjectively observed each of the labs during the progression of PBL activities though a weekly journal writing as the unit progressed. This unit was taught during the first semester of the school year in seventh grade and up to this point in the school year the students had little experience with problem based learning. It was expected that the first PBL 1 *Dissolving Sugar* (Appendix E) would have been the most difficult for the students to accomplish because of the large amount of student led learning compared to the standard teacher guided inquiry approach in the prior weeks. The first PBL activity was difficult for students in all four teaching hours the first day with many students asking the teacher directly to just give out the answer. Many students wanted to rush through the Problem Starter (Appendix A) and develop their lab procedures. Many students wanted to progress directly to the lab with little or no thinking about what they were going to accomplish. Once in lab for PBL 1 there were many times when the teacher needed to redirect students to get back on track with what their procedures asked them to do. Many students had an unclear vision of what they needed to accomplish due to a lack of knowledge of the importance of a quality procedure.

In comparison, PBL 2 and 3, the students were actively engaged in their Problem Starter (Appendix A) and had begun to understand the amount of work that was necessary to complete before any laboratory work could be started. In the second PBL 2, there was a noticeable difference in student engagement because of a general "buzz" in the room of students trying to research how to solve the problem on their own or with the help of other students. There was an internal motivation factor in the class compared to the first PBL. Once in the lab setting after completing the Problem Starter for PBL 2, students were more involved in sharing tasks students needed to do to accomplish their plan. Two of the classes were highly motivated at working together, but in general the second two classes of the day seemed to struggle as classes in figuring out how to properly work together to finish their lab while actually understanding what they were doing.

By the time PBL 3 was started, students had an understanding of classroom expectations for the PBL process from the beginning of the Problem Starter (Appendix A), through writing their lab procedures, and into the actual lab activity. Students had a noticeable understanding of the amount of work that was student led and not the teacher directing, but serving as a facilitator of the class. For PBL 3, 4, and 5 students were highly motivated to complete the process of each PBL. According to the teacher weekly journal, a noticeable amount of behavior problems diminished the further along in the unit. Students were well aware of classroom expectations and accountability. Student work groups were holding one another accountable for the lab results, being more careful of accuracy and precision.

In the fourth and fifth PBL activities on *Stinky Drains* (Appendix H) and *Air Bags* (Appendix I), students in general had a greater interest and genuine care for their own lab work. Students were checking one another's paperwork, data tables, measurements, and holding each other accountable, rather than the teacher having to do all the motivating. Students were at times almost angry with another group member if they improperly measured a volume or mass because they knew they wanted their group results to be the best and to help them solve the problem they were working towards.

**Formative Assessment**

In between Lab 4 *Stinky Drains* (Appendix H) and Lab 5 *Air Bags* (Appendix I), the teacher used an activity (Appendix M) using paperclips to model atoms before and after a chemical change. Students were expected to identify the reactants and products of the basic reaction of Lab 4 and Lab 5 of baking soda and vinegar. For each atom of the equation, students represented a different color paperclip for each type of atom. Students were able to easily identify how many atoms were present on both sides of the equation before and after the reaction. Students placed these paperclips on their desks in groups of four students and worked together to display the reactions. Many students were actively engaged with their group in counting paper clips and placing them in the correct compound or molecular shapes. Students in all classes commented on being able to see the atoms would be helpful in learning this material and the paper clips helped them "see" what was going on in the reaction. Some students in every class were also hesitant to place paper clips because they were unsure of the correct shape of the molecules. Students at this grade level are expected to know mass is conserved before and after the reaction and were able to correctly at all tables in the classroom develop a correct model showing the same number of paper clips on the reactant side as the product side of the equation. Many students asked questions of what shape the molecules should look like exactly and how to correctly connect the paper clips. The goal of the teacher was not to have students understand molecular shape, but rather conservation of mass.

Each student completed the SurveyMonkey® survey (Appendix C) before and after this study began. The survey was also given to students after the unit test. Table 6 shows the pre and posttest averages for key questions on motivation, confidence, and science ability. The first number listed under each category is the percentage before the unit began, and the second number listed after the ( / ) mark would be the percentage after the unit was finished.

Table 6 Survey Monkey

| Question | Strongly Disagree | Disagree | Neither Agree Nor Disagree | Agree | Strongly Agree |
|---|---|---|---|---|---|
| **1. I am good at science** | **3 / 1** | **7 / 0** | **30 / 33** | **52 / 51** | **8 / 13** |
| 2. I enjoy science | 0 / 5 | 6 / 8 | 17 / 18 | 43 / 46 | 34 / 23 |
| 3. Doing science projects or activities makes me nervous or upset | 25 / 26 | 45 / 36 | 16 / 18 | 8 / 13 | 6 / 8 |
| 4. I do not worry about how well I do on science tests | 40 / 47 | 31 / 37 | 11 / 5 | 14 / 8 | 5 / 3 |
| 5. I often get scared when I see problems that involve math in science class | 23 / 26 | 36 / 28 | 17 / 20 | 14 / 21 | 9 / 5 |
| **6. I learn science best by doing labs** | **2 / 0** | **4 / 3** | **23 / 26** | **37 / 44** | **34 / 28** |
| 7. I learn science best by direct teacher instruction | 7 / 13 | 13 / 18 | 35 / 33 | 37 / 26 | 8 / 10 |

Table 6 shows the before and after results from a survey given to students. The number listed first is the pre unit percentage and the second number listed is the post unit percentage.

Table 6 (cont'd)

| | | | | | |
|---|---|---|---|---|---|
| 8. I learn science best when I work with a group | 8 / 8 | 16 / 8 | 19 / 30 | 37 / 41 | 19 / 13 |
| 9. I learn better when I am given the opportunity to figure out things by myself | 14 / 13 | 19 / 26 | 31 / 27 | 31 / 23 | 6 / 13 |
| 10. Doing science helps a person think | 0 / 0 | 13 / 18 | 32 / 29 | 44 / 42 | 10 / 11 |
| 11. It is important to know science to get a good job | 2 / 0` | 5 / 3 | 42 / 34 | 38 / 42 | 12 / 21 |
| 12. Knowing science will help me make good decisions | 2 / 8 | 14 / 21 | 52 / 32 | 22 / 26 | 9 / 13 |
| **13. I learn more by studying science or problems that interest me** | **2 / 0** | **7 / 5** | **19 / 24** | **51 / 53** | **21 / 18** |
| **14. Using real life problems or examples helps me learn science** | **4 / 3** | **14 / 11** | **26 / 29** | **44 / 47** | **12 / 11** |
| 15. I get nervous when presenting in front of others | 7 / 11 | 14 / 21 | 23 / 21 | 22 / 24 | 34 / 24 |
| 16. I worry that group work often allows some people to slack off | 6 / 3 | 11 / 8 | 23 / 34 | 36 / 32 | 24 / 24 |
| 17. I worry I won't work well together in groups | 21 / 24 | 33 / 47 | 24 / 16 | 13 / 5 | 10 / 8 |

The survey given to students before and after the unit was the same survey questions. The first survey question of “I am good at science” is important to look at for this PBL study because students were doing a process of science and it is important to feel confident in student lead learning to keep motivation. 8% of students strongly agreed before unit and 13% of students strongly agreed after completing the unit that they were good at science. Questions 13 and 14 on the survey were related to the student interest in the problem and also relating the problem to real life. In question 13 more than 70% agreed or strongly agreed before and after the unit which shows that students in their opinions learn more by doing problems that interest them. In question 14 more than 55% agreed or strongly agreed before and after the unit which shows students felt they learned science better by doing real life problems. This is important to note that students felt this was important before and after the unit was completed.

## Discussion and Conclusion

The data collected (Figure 1, Table 3) from this study demonstrated the power of problem based learning in the middle school science classroom. This study verified findings of David Jonassen's research (1997) of using ill structured problems in Problem Based Learning. In this study at Dowagiac Middle School the use of ill structured problems allowed students to make multiple pathways of learning to figure out a solution to open ended questions. This type of teaching benefited students in a direct and formative way that allowed students to take the initiative and develop their own a pace of learning. Students in problem based learning understand by engaging in a process. In this study it was very powerful as well to have hands on activities where students were held accountable to produce results that they could physically see and measure with scientific instruments.

The students in this middle school study were consistent with the research from Ferreira and Trudel, (2012) where students were more likely to be motivated to achieve learning if they are under control of their pathway of learning. This was evident in the Problem Based Learning study at Dowagiac Middle School because of the different ways students achieved their answers in the problems presented to students. Each group of students did not research the same information, develop the same hypotheses, create the same experiments, or even realize the same conclusions. Since students found their own answers to the presented problem, they were motivated to draw conclusions at the end from their laboratory findings and connect their data to the initial problem at hand. Students' learning pathways were individualized by the students themselves with the help of the instructor.

As previously stated in the Results, motivation was not the same for all four class periods of the day in this study. Students in the first two hours of the day were highly motivated and less facilitation was necessary for these two hours. They worked more independent from the teacher and also from other groups in the classroom. The third and fourth hours of the day seemed to struggle with the process of science for each PBL lab 1 through 5. The instructor needed to be more of a facilitator to these afternoon hours. There could be two possible causes of this division in learning from the morning to the afternoon classes. The instructor noticed lack of math confidence in the afternoon hours compared to the morning hours. Students who are not as confident in their math skills often will struggle with their science confidence as well when it comes to laboratory work where measurements, data tables, and simple calculations are necessary. This could be because the morning hours had more higher level math students compared to the afternoon hours. Some of the students in the morning hours are in the advanced math classes during the day. The teacher noticed that students in the afternoon did not have as much confidence in their math skills. This could have accounted for the lack of science confidence in the afternoon classes because the problems encountered in this study had a connection to critical thinking and computational math skills.

Each of the lab reports that the students completed were identical in their format in terms of what the students were expected to write. This has both positive and negative aspects. Having the same standard lab write up for each lab was great for seeing improvements in their learning, writing ability, and understanding of the process of science. From the viewpoint of the teacher, it was simple to determine the students' improvements in their conceptual thinking. The teacher could look at all of the student's labs next to one another and see a progression or digression in their writings. Having the same lab report template to fill out helped the students when explaining their thinking from lab to lab. The "SET" lab report designed in the introductory chemistry class at University of Leicester and used in this middle school study was key for analyzing data through this research project. (Williams et al. 2009). It allowed students to understand a set format of thinking which gave them the scaffolding they needed in a middle school.

One of the negatives of this lab report template was its length. Some of the students became disinterested in the length of the report by the end of Labs 4 and 5. Many knew that it did take "process and time" to make their way through the first research section of the report. By the end of this unit there were students in the classes who were complaining about having to write out so many things even before they were allowed to go into the lab. This is comparable to the findings of Kolodner et. al (2003) with middle school students not having enough drive and mental capacity to fully investigate the problems presented. According to the Kolodner study, students in middle school need guidance in the PBL process and the Problem Starter (Appendix A) was an excellent way of allowing students to follow directions but still have room for their own thoughts into their lab design.

Many students were interested in the research portion of each PBL because they were learning new material and it was relevant to their lives. Students who did take the time to research the appropriate information and asked quality questions about the presented problem were able to easily set up their pre lab write up. They were also able to write out their lab procedures and develop appropriate hypotheses. Many students complained about the amount of work that needed to be done in order to get through the entire PBL process from the beginning of a Problem Starter (Appendix A) and through their Experimental Design. However, their interest was genuine and continued through the entire process of learning, regardless complaints about the amount of writing. For some of the students the quality of their writing decreased as the unit continued because they knew the reward of finishing the Problem Starter was to enter into the hands on lab. Again, this relates to findings Kolodner et al. (2003) where students in middle school have a smaller mental capacity to fully develop their thinking in the PBL process. Students in Dowagiac Middle school were motivated to achieve their goals, but were also influenced by other social reasons to complete the labs and find solutions to the problems. There seemed to be competition among the students to get the problem solved before any other groups. There was a sense of accomplishment among the students who did verify their hypothesis.

The teacher of this PBL study will continue to use Problem Based Learning in future years for this unit of chemical and physical change. This style of learning created an environment in the classroom that allowed students to feel comfortable in asking questions that normally they may not have asked. Students were engaged in the problems and had a genuine interest in what they were researching. Students worked side by side with group members and worked together to accomplish each task and problem given to them. The students in the classes asked the teacher questions about how to use lab equipment properly so they would be able to accurately measure parameters and get good results because they wanted to find out the answer of the PBL. The teacher found that by teaching using PBL methods it was easy to reach and speak to all students every day of class by circulating around and having more individual conversations with groups or students. This made more students feel welcome and comfortable learning and asking tough questions through the process. Using this method allowed the teacher to get to know students on a personal level because every day in lab and during Problem Starter (Appendix A) students talked to either the teacher or to multiple students. It was very difficult for students to get through the hour without having conversations with the teacher.

The teacher would like to add to the problem based learning experience by having students generate graphs on Chrome Book® computers. During this unit the students tried to use the computers during Lab 4 and Lab 5 for graphing and data collection. However, many of them were unable to multi task, completing their actual lab work and the using computers at the same time. Future implementations of this unit will need to have more guidance on how to input data into Excel® sheets. For this unit, students were given pre written Excel sheets and they only needed to input the data into the correct cells. This was a challenge to students because they never had used the program before. This caused management problems due to frustrated students asking many questions. In order help improve this process it would be helpful for students to use the program before this unit begins to be more efficient. All five of the labs in this unit were the first time the teacher had used these activities in a classroom and the amount of time for each activity did take longer to complete than expected. All five labs were a success because students were actively engaged in the process, and statistically (Table 3, Figure 1) the students improved their content knowledge, and their ability to use the scientific process.

The teacher plans to develop more PBL based units for not only the 7th grade class, but also for 8th grade. One challenge could be to find ways to use the PBL process with less writing. Students began to dislike the large amounts of writing involved in this unit. Writing has value in science and is important for middle school students according to Michigan State Standards, Common Core, and Next Generation Science Standards. However, developing a more efficient Problem Starter (Appendix A) and lab write up would be useful as it would give more time for investigations using the PBL process and also give more classroom time for future problem based learning experiences. The main reason for multiple writing prompts was to show improvements in students thinking in a measureable way. In the future the teacher would like to find a way to get students thinking at the same cognitive level as what is displayed in their writings, but possibly discussing their thinking as a group. Using more of a collaborative approach to sharing ideas around the classroom could help build knowledge on a specific problem presented to groups. The way this unit was designed was for groups to work independently from one another. It should be possible to devote more time to presenting findings in the PBL process to other class mates that could benefit all students specifically those who had challenges researching and developing reasonable experiments. Sharing ideas among groups would keep those students who “may feel” left out of behind interested.

Using problem based learning in the middle school classroom will be used in the future by this teacher. The use of PBL showed a positive impact in students’ interest in science, their knowledge of content, and their understanding of the scientific process. These skills can be used throughout their entire middle school career and also will help prepare them for high school classes and curriculum. The overarching use of writing, math, science, and collaboration in this unit helped build student confidence in other core curriculum. These benefits were clearly evident to the teacher and students involved.

APPENDICES

APPENDIX A

Scientific Process Log

Problem Starter

**<u>Existing Knowledge: What do you know?</u>** (Summarize the problem, explanation of words or scientific ideas, potential explanations of problem, brainstorming)

**<u>Learning Issues: What questions do you have about the problem?</u>**

**<u>Course of Action: What did you find out in research?</u>**

## Experiment Design

**Hypothesis Statement**

| |
|---|
| |

**Testing Ideas**

| | |
|---|---|
| <u>What do you want to find out?</u><br><br><u>What is your control if you have one?</u><br><br><u>What are your variables?</u><br>Dependent:<br>Independent:<br><br><u>How many tests and trials?</u><br><br><u>Where are you recording your data?</u> | <u>Step by Step Procedure</u> |
| <u>Drawing of your experiment</u> | |

**Data Collection**

| |
|---|
| Observations |
| Data Table |
| What's Next?  (What modifications can you now change from what you learned?)<br><br>What new questions have you come up with since experimenting? |

Appendix B

Parental Consent and Student Assent Form

Dear Students and Parents/Guardians:

I would like to take this opportunity to welcome you back to school and invite you to participate in a research project; **Problem based Learning and the Scientific Process** which I will conduct as part of the first semester of this course. My name is Mr. Dan Schuchardt and I am your science teacher for this year. I am also a master's degree student at Michigan State University. Researchers are required to provide a consent form like this to inform you about the study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researcher any questions you may have.

**What is the purpose of this research?** I have been working on effective ways to teach the process of science using problem based learning and I plan to study the results of this teaching approach on student comprehension and retention of material. The results of this research will contribute to the teacher's understanding about the best way to teach about science topics. Completion of this research project will also help me earn my master's degree in Michigan State University's College of Natural Science.

**What will students do?** Students will participate in the usual instructional curriculum for 7$^{th}$ grade general science but with added emphasis on problem based learning. Students will complete the usual assignments, laboratory experiments and activities, class demonstrations, and pretest/posttest just as they would do for any other unit of instruction. There are no unique research activities and participation in this study will not increase or decrease the amount of work that students do. I will simply make copies of student's work for research purposes. This project will take place in the fall semester of 2014-15. I am asking for permission from both students and parents/guardians (one parent/guardian is sufficient) to use copies of student work for my research purposes.

**What are the potential benefits?** My reason for doing this research is to learn more about improving the quality of science instruction. I will not know about the effectiveness of my teaching methods until I analyze my research results. If the results are positive, I can apply the same teaching methods to other science topics taught in this course, and you will benefit by better learning and remembering of course content. I will report the results in my master's thesis so that other teachers and students can benefit from my research.

**What are the potential risks?** There are no foreseeable risks associated with completing course assignments, laboratory experiments and activities, class demonstrations, and pretest/posttests. In fact, completing coursework will be very beneficial to students. Another person will store the consent forms (where you say "yes" or "no") in a locked file cabinet that will not be opened until after I have assigned the grades for the semester. That way I will not know who agrees to participate in the research until after grades are issued. In the meantime, I will save all written work. Later I will analyze the written work for students who have agreed to participate in the study and whose parents/guardians have consented.

**How will privacy and confidentiality be protected?** Information about you will be protected to the maximum extent allowable by law. Students' names will not be reported in my master's thesis or in any other dissemination of the results of this research. Instead, the data will consist of class averages and samples of student work that will not include names. After I analyze the data to determine class averages and choose samples of student work for presentation in the thesis, I will destroy the copies of students' original assignments, tests, etc. The only people who will have access to the data are me, my thesis committee at MSU, and the Institutional Review Board and MSU. The data will be stored on password-protected computers (during the study) and in locked file cabinets in Dr. Heidemann's locked office at MSU (after the study) for at least three years after the study.

**What are your rights to participate, say no, or withdraw?** Participation in this research is completely voluntary. You have the right to say "no." You may change your mind at any time and withdraw. If either the student or parent/guardian request to withdraw, the student's information will not be used in this study. There are no penalties for saying "no" or choosing to withdraw.

**Who can you contact with questions and concerns?** If you have questions or concerns about this study, please do not hesitate to contact:

| | |
|---|---|
| Mr. Dan Schuchardt | Dr. Merle Heidemann |
| Dowagiac Middle School | 118 North Kedzie Lab |
| 57072 Riverside Dr | Michigan State University |
| Dowagiac, Mi 49047 | East Lansing, MI 48824 |
| dschuchardt@dowagiacschools.org | heidma2@msu.edu |
| (269)-782-4440 ext. 1169 | (517) 432-2152 ext. 107 |

If you have questions or concerns regarding your role as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if desired, MSU Human Research Protection Program at: **irb@msu.edu**

**How should I submit this consent form?** Please compete the attached form. Both the student and parent/guardian must sign the form. Please return with your student a form indicating interest either way. **Please return this form in a sealed envelope to Mr. Schuchardt room, B111 by Monday 15 September 2014.**

**Parents/guardians should complete this following consent information:**

I voluntarily agree to have ______________________________________________________
participate in this study. (Student Name)

**Please check all that apply:**

**Data:**

__________ I give Mr. Dan Schuchardt permission to use data generated from my child's work in this class for this thesis project. All data shall remain confidential.

__________ I do not wish to have my child's work used in this thesis project. I acknowledge that my child's work will be graded in the same manner regardless of participation in this research.

**Photography, audiotaping, or videotaping:**

__________ I give Mr. Dan Schuchardt permission to use photos or videotapes of child in the class room doing work related to this thesis project. I understand that my child will not be identified.

__________ I do not wish to have my child's images used at any time during this thesis project.

___________________________________________________________________

(Parent Signature) (Date)

___________________________________________________________________

(Student Signature) (Date)

**Important: Please return this form in the sealed envelope to Mr. Schuchardt's room by Monday 15 September 2014**

Appendix C

Survey Monkey®

| Question | Strongly Disagree | Disagree | Neither Agree Nor Disagree | Agree | Strongly Agree |
|---|---|---|---|---|---|
| I am good at science | | | | | |
| I enjoy science | | | | | |
| Doing science projects or activities makes me nervous or upset | | | | | |
| I do not worry about how well I do on science tests | | | | | |
| I often get scared when I see problems that involve math in science class | | | | | |
| I learn science best by doing labs | | | | | |
| I learn science best by direct teacher instruction | | | | | |
| I learn science best when I work with a group | | | | | |
| I learn better when I am given the opportunity to figure out things by myself | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Doing science helps a person think | | | | | |
| It is important to know science to get a good job | | | | | |
| Knowing science will help me make good decisions | | | | | |
| I learn more by studying science or problems that interest me | | | | | |
| Using real life problems or examples helps me learn science | | | | | |
| I get nervous when presenting in front of others | | | | | |
| I worry that group work often allows some people to slack off | | | | | |
| I worry I won't work well together in groups | | | | | |
| Name | | | | | |

APPENDIX D

Test- Physical and Chemical Changes

Name_________________________

1. Which of the following is an example of a physical change?
   a. Ice melting
   b. Wood burning
   c. A car rusting
   d. Food being digested in your stomach

2. Which of the following is an example of a chemical change?
   a. Water in a pot boiling
   b. Chopping wood
   c. Fireworks exploding
   d. Spilling water

3. In a chemical reaction, the mass of the reactants equals the mass of the products. This is
   a. The law of science
   b. The law of conservation of mass
   c. The law of products
   d. The law of energy

4. Which of the following statements about chemical changes is **not** true?
   a. The original substances in a chemical reaction are called reactants.
   b. The substances produced in a chemical reaction are called reactants.
   c. During a chemical change, a new substance with new physical and/or chemical properties is produced.

5. Which of the following would result with the addition of heat energy to a liquid?
   a. The molecules in a liquid would begin to move faster.
   b. The molecules in the liquid would begin to move slower.
   c. The molecules in the liquid would continue to move at the same speed.

6. A change that alters the form of a substance without changing it into a new substance is called a(n):
   a. Physical change
   b. Chemical change
   c. Thermal change
   d. Energy change

7. One example of changing a substance physically is:
   a. Burning paper
   b. Baking cookies
   c. Burning table sugar
   d. Dissolving sugar in water

8. A physical change results in______.
   a. Heat, smoke, fizzing
   b. New substances with different properties
   c. No new substances
   d. Changes in pressure

9. One example of changing a substance chemically is_____.
    a. filtering water
    b. weathering gravestones with acidic rain
    c. boiling water
    d. cracking cement from frost

10. What always happens as a result of a chemical change?
    a. Change of state.
    b. Two or more substances are combined to form a new substance.
    c. The same substance appears in a different state of matter.
    d. One substance breaks into two of the same substances.

11. During chemical reactions, energy can be _____.
    a. Shown by heat
    b. Created or destroyed
    c. Condensed
    d. Not involved

12. When water freezes, it undergoes ____?
    a. Physical Change
    b. Chemical Change
    c. Neither, it does not change

13. In chemical reactions, what does the principle of conservation of matter mean?
    a. Matter is not created or destroyed
    b. The total mass of the reactants is greater than the total mass of the products
    c. The total mass of the reactants is less than the total mass of the products

Indicate whether the changes listed below are chemical change or physical change. Write C or P

14._____ fireworks exploding
15._____ dissolving food coloring with water
16._____ condensation on grass
17._____ salt dissolving in water
18._____ iron rusts in a damp environment
19._____ mixing calcium chloride water and baking soda
20._____water turning into water vapor
21._____mixing baking soda with vinegar to unclog a drain
22._____lighting a match

**Data Analysis**

Scientists at SMC wanted to prove the Law of Conservation of Mass. Figures 2 and 3 show the results from their experiments A through F.

Figure 2 $CO_2$ production

| Lab Reaction | Starting Mass (g) Reactants | Final Mass (g) Products | Amount of $CO_2$ (g) |
|---|---|---|---|
| A | 123.6 | 123.6 | 7.5 |
| B | 253.7 | 253.7 | 15.3 |
| C | 234.6 | 234.1 | 13.4 |
| D | 235.8 | 235.1 | 13.6 |
| E | 125.4 | 125.4 | 7.6 |
| F | 263.2 | 263.2 | 16.0 |

Figure 2 shows CO2 production from scientists at SMC during Conservation of Mass testing.

Figure 3 Type of Reaction Change

| Lab Reaction | Starting Color | Color Change | Fizzing |
|---|---|---|---|
| A | Blue | Blue | No |
| B | Blue | Pink | Yes |
| C | Red | Pink | Yes |
| D | Blue | Blue | No |
| E | Blue | Red | Yes |
| F | Blue | Blue | No |

Figure 3 shows type of reaction change depending on color and fizzing.

23. _____Which reactions prove the Law of Conservation of Mass?

a. A, B, D, F
b. A, B, E, F
c. B, C, F, A
d. C, D, E, F

24. _______$CO_2$ gas was produced from all of the reactions. What patterns exists between the amount of Reactants and the amount of $CO_2$ released.

a. The greater the amount of reactants, the greater the amount of $CO_2$produced
b. The greater the amount of reactants, the less the amount of $CO_2$ produced
c. Having less reactant (mass) creates more $CO_2$

25. ______Which reactions did not change color?

a. A, B, C
b. B, C, A
c. A, D, F
d. D, F, E

Essay: Answer the following questions in complete sentences. Explain each answer fully.

1. A saltwater fish tank was being cleaned and left in the Sun. After a few days, the solution disappeared and a white residue remains on the tank. Has a physical or chemical change taken place? Explain.

___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________

2. On a balance, a student measures the total mass of an antacid, and a beaker of water. The antacid is then placed in the beaker of water and bubbles form as the antacid disappears. The mass of the final solution is less than the initial mass. Is this an exception to the law of conservation of mass? Explain.

___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________

3. Describe three pieces of evidence that you could use to prove that a chemical reaction has taken place.

___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________

APPENDIX E

PBL 1: Dissolving Sugar

"Your Kool-Aid is always nasty, it just tastes like water," said Mike as he put the container back in the fridge because clearly he was not going to drink another glass. He took one more swig from his glass and tossed it all down the drain!

"Why did you just waste that Kool-Aid Mike? If you think you can do better then go ahead and do it yourself! I'll just tell you that we do not have that much sugar left, so you are limited on how much you can put in your batch." Mike's big brother constantly was annoyed by Mike. "If you think you are so good at it Mike then figure it out without overdoing it on the sugar!"

What steps can be done to solve this problem?

APPENDIX F

PBL 2: Kitchen Box

Thankfully you have moved across town into a larger house but unfortunately you are the one who has to help unpack everything from the moving truck. A box labeled KITCHEN was not too heavy for you so you carry it into the house. As you're walking your younger annoying brother trips you and the box falls onto the dirt driveway! Upset, you make him carry the box into the kitchen for you.

As you were unpacking the family's kitchen supplies like flour, salt, sugar, baking powder, pepper, and other items you begin to notice that the fall you took spilled some of these things onto the bottom on your box. There is salt, many popcorn kernels, poppy seeds, and yuck, some iron pills that were broken up into small pieces from your sisters iron pills. She takes those crushed iron pills for her anemia. It is possible you can save these items but they are clearly mixed…in the dirt!

What steps can be done to solve this problem?

APPENDIX G

PBL 3: Melting Wax

“Why are you always burning so many candles?  They just smell up the house and makes my nose all stuffed up.”  Sarah was not a fan of burning candles and she constantly was asking her mother to stop lighting them so often.

Sarah though was wondering about a few things that she just could not understand.  She was a very curious 8 year old who constantly asked questions.  She picked up a new candle that her mother had not burned yet and was looking at it very carefully. “Hey Mom, how do they get the this white string on the inside of this candle?  It is almost like a popsicle stick yah know Mom, but it’s not frozen like a popsicle is frozen around the stick.”

She knew candles turn to water like stuff when they get hot but did not get how they could go back to a candle shape without being put in the freezer.  How can you help Sarah?

What steps can you take to solve this problem?

APPENDIX H

PBL 4: Stinky Drains

"Ughhhh soo gross! The sink is clogged again!" yelled Tom from the upstairs bathroom. "I'm so sick of this thing clogging up."

"Oh hush," yelled back his sister Kelsey who was constantly getting the blame from Tom for shedding like a dog. "I've got a trick for fixing the drain that is natural, friendly to the environment, and we even have it here in our kitchen. Oh yeah, and it will not harm the pipes at all, so let me take care of it and you can stop your whining!"

Tom was always growing impatient with his sister. "Whatever just fix it so I can brush my teeth…you know I've got a date tonight!"

What do you think she's going to do?

What steps can be done to solve this problem?

APPENDIX I

PBL 5: Air Bags

**Article #1**

**Breaking News: Airbag Fails to Deploy After Man Strikes Telephone Pole**

6/19/2014 10:51am

In a recent accident just north of Dowagiac on M51, twenty four year old Michael Angler's car struck a deer, causing his car to veer off the road and crash into a telephone pole. No significant injuries to Michael were reported and no other cars were involved in the accident. Michael was taken to the hospital for further testing and treatment of minor cuts from broken glass in the collision.

After investigation of his car at Hanks Auto Body, it was reported that there was an air bag failure in Mr. Angler's car which should have deployed with this collision. It is not understood yet as to why the air bag did not work but it is thought that there could be a malfunction in the chemistry behind the wheel of his car. Further investigations will be necessary as this is the $8^{th}$ reported incident in Michigan of the airbag failure in the same model car the S-150.

What possible reasons are there for Mr. Angler's airbag to not inflate during this crash?

**Article #2**

**Breaking News: Car Company Recalls S-150 for Mistake in Chemistry**

7/22/2014 9:10am

Car Company recalls 11,000 S-150 model cars due to failure in air bag chemistry. A design flaw caused an incomplete chemical reaction to take place. The failure causes a lack of Nitrogen gas production needed for the air bag to inflate, leaving also a harmful chemical exposed within the car that otherwise would have reacted in inflate the airbag. Car Company is seeking alternative air bag deployment designs to avoid future accidents.

Design an experiment that uses a reaction to inflate an airbag. You have limited resources (Baking soda and Vinegar) and your product must inflate the airbag without over inflating the bag and also resist impact.

Your goal is to show that all materials you started with are still in place after the collision and no gas has been released.

APPENDIX J

Problem Starter Grading Rubric

Student Name: ________________________________________

| CATEGORY | 2 | 1 | 0 |
|---|---|---|---|
| Existing Knowledge: What do you know? | Fully brainstorms by expressing previous knowledge, unpacks and summarizes the problem | Partially brainstorms by expressing limited previous knowledge and shows limited thoughts on summarizing the problem | Does not express previous knowledge and shows incomplete thoughts on summarizing the problem |
| Learning Issues: Need to Know? | Fully generates thoughtful questions | Partially generates thoughtful questions | Does not generate thoughtful questions |
| Course of Action: Research Findings? | Fully researches showing understanding of topic questions | Partially researches topic questions, incomplete understanding | Does not produce research information on topic questions relevant to questions |

APPENDIX K

Experiment Design Report Grading Rubric

Student Name: _______________________________________

| CATEGORY | 2 | 1 | 0 |
|---|---|---|---|
| Hypothesis Development | Developed a hypothesis well supported by reasoning. | Developed a hypothesis somewhat supported by reasoning. | Developed an incomplete hypothesis with little or no reasoning. |
| Testing Idea | Independently identified a question which was interesting to the student and which could be investigated. | Identified, with adult help, a question which was interesting to the student and which could be investigated. | Unable to identify a question which could be investigated. |
| Variables | Independently identified and clearly defined which variables were going to be changed (independent variables) and which were going to be measured (dependent variables). | Somewhat identified which variables were going to be changed (independent variables) and which were going to be measured (dependent variables). Reversed independent and dependent but did identify variables. | Unclearly identified and defined which variables were going to be changed (independent variables) and which were going to be measured (dependent variables). |
| Description of Procedure | Procedures were clearly outlined in a step-by-step fashion that could be followed by anyone without additional explanations. | Procedures were somewhat outlined in a step-by-step fashion that could be followed but needs additional explanations from students. | Procedures were not outlined in a step-by-step fashion, and had incomplete gaps that require explanation in order to repeat procedure accurately. |
| Diagrams | Provided an accurate, easy-to-follow diagram with labels to illustrate the procedure or the process being studied. | Provided an easy-to-follow diagram with minimal labels to illustrate the procedure or process, but a few key steps are left out. | Did not provide a diagram OR the diagram was quite incomplete. |

| | | | |
|---|---|---|---|
| Conclusion/ Summary | Student provided a detailed conclusion clearly based on the data and related to previous research and the hypothesis. | Student provided a conclusion with some reference to the data and the hypothesis statement(s). | No conclusion was apparent OR important details were overlooked. |
| What's next? | Student provided detailed questions furthering the investigation. | Student provided questions that somewhat furthers the investigation. | Student did not provide useful questions for furthering investigation. |

APPENDIX L

Essay Questions Pre/Post Test Rubric

| CATEGORY | 3 | 2 | 1 |
|---|---|---|---|
| Essay Question 1 | Writing fully explains how salt water solution evaporates leaving salt and this is a physical change. | Writing incorrectly explains water solution evaporates leaving salt OR does not identify physical change | Writing incorrectly explains water solution evaporates leaving salt AND does not identify physical change |
| Essay Question 2 | Writing fully explains how antacid tablet goes through a chemical change and mass is released into the air | Writing describes how antacid tablet goes through a chemical change but does not explain mass is released into the air | Writing is incomplete and does not show knowledge of chemical change or what happened to the mass |
| Essay Question 3 | Describes three pieces of evidence for chemical change | Describes two pieces of evidence for chemical change | Describes one piece of evidence for chemical change |

APPENDIX M

Paper Clip Modeling Reactions

Learning Objective:

1. Students will be able to create models to represent the atoms of chemical reactions.
2. Students will be able to understand the total number of atoms does not change in a chemical reaction and mass is conserved.

**Directions**: Model the chemical equations below using paperclips. Each paperclip represents one atom. Follow the first example below.

The following reaction is of baking soda and vinegar (acetic acid and sodium bicarbonate) reacting to form sodium acetate, water, and carbon dioxide.

$$CH_3COOH + NaHCO_3 \rightarrow NaC_2H_3O_2 + H_2O + CO_2$$

Assing colors to each type of atom.

Carbon =

Hydrogen =

Sodium =

Oxygen =

How many Carbon atoms are on the LEFT side of this equation (reactant side)? ______

How many Hydrogen atoms arethere on the LEFT side of this equation (reactant side)? ______

How many Sodium atoms arethere on the LEFT side of this equation (reactant side)? ______

How many Oxygen atoms arethere on the LEFT side of this equation (reactant side)? ______

**On your desk, attempt to make $CH_3COOH$ with your paperclips first and show your teacher.**

**Once you have approval, model $NaHCO_3$.**

How many Carbon atoms are on the RIGHT side of this equation (product side)? ______

How many Hydrogen atoms arethere on the RIGHT side of this equation (product side)? ______

How many Sodium atoms arethere on the RIGHT side of this equation (product side)? ______

How many Oxygen atoms arethere on the RIGHT side of this equation (product side)? ______

**Leaving the paperclips you created, now attempt to make $NaC_2H_3O_2$ with your paperclips and show your teacher. Once you have approval, model $H_2O + CO_2$ to complete the reaction.**

1. What pattern do you notice about the number of paper clips on the left and right side of the equation?

2. Why do you think that the amount of products equals the amount of reactants?

3. How many total atoms are there on the reactant side? How many total on the product side?

4. Are all of the atoms in this reaction accounted for? Why or why not?

Extension: Show the following equations using paperclips. First write down your designated colors for each element.

<u>Photosynthesis Reaction</u> Light+ $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

Carbon =
Hydrogen =
Oxygen =

<u>Cellular Respiration</u> $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

Carbon =
Hydrogen =
Oxygen =

<u>Hand Warmers</u> $CaCl_2 + 2\ NaHCO_3 \rightarrow CaCO_3 + 2NaCl + H_2O + CO_2$

Carbon =
Hydrogen =
Oxygen =
Calcium =
Chlorine =
Sodium =

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