Investigating Problem Based Learning in the Science Classroom

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Investigating Problem Based Learning in the Science Classroom

Abstract
The level of engagement among students during problem-based learning (PBL) was investigated. PBL is a teaching strategy that provides students with real-life experiences which in turn creates enthusiasm among students and provides students with a deeper level of understanding of the content. The level of engagement was determined by a triangulation of data that included student reflections, observational data and classroom discussions. During the PBL lessons students were more actively involved in their learning and the results indicated that students were more engaged during PBL lessons than traditional lecture-based lessons.

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Investigating Problem Based Learning in the Science Classroom

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Investigating Problem Based Learning in the Science Classroom

This paper will look into Problem Based Learning (PBL) in an effort to enhance student engagement in the classroom. PBL is a teaching approach that is focused on student engagement through hands-on, authentic scenarios where students must use critical thinking and problem-solving skills to approach the situation (Delisle, 1997; Torp & Sage, 2002; Kendler & Grove, 2004).

When using PBL in the classroom, students encounter a realistic approach to the content. Through the process of PBL students are able to approach the subject matter through hands-on activities. The PBL scenario, which is provided by the teacher, brings the real-world into the classroom. When students encounter such realistic problems that directly affect them, students become more engaged with the subject matter and develop a deeper level of understanding as well. Throughout the process students develop several skills essential to life outside of school. Such skills include: formulating ideas, questioning, critical thinking, brainstorming, organizing, researching, observing, analyzing, summarizing and problem-solving.

Following is a literature review of PBL. It investigates the process of PBL and how it has been implemented into the classroom to increase student engagement with the subject matter, especially in the science classroom.

To investigate the power of PBL on student engagement in the science classroom, several lessons were implemented throughout the year. One General Chemistry class, one Science 8 and two Regents Living Environment classes encountered PBL lessons sporadically throughout the year. Each class followed the curriculum set forth by the
Rochester City School District and New York State, as well as content standards and objectives for each subject area.

To investigate engagement and understanding with the given content area during PBL lessons, students wrote anonymous reflections about the lessons they had encountered. Also noted, were unprompted discussions between students and their peers as well as the instructor.
Literature Review

Educators began using PBL, as well as inquiry-based lessons to enhance student understanding with the content and to create meaning for the students. Through a hands-on approach, students become active learners and engaged with the material. This literature review will explore the history of PBL, what it is, why educators are implementing PBL and its role with inquiry. Also included are examples of PBL’s that have been implemented into the science curriculum. The role of PBL through interdisciplinary means as well as inquiry is also discussed.

History of PBL in the Classroom

Problem Based Learning was first introduced into the classroom through education in the medical setting. According to Torp and Sage (2002), McMaster University in Ontario, Canada first introduced the idea to their medical students in the 1960’s. Medical students were having a hard time recalling and applying skills, in the clinical setting, which had been taught through lecture-based lessons. Previously, medical students were required to memorize information to pass the test and then try to apply it to the clinical setting (Delisle, 1997). When practicing medicine on their own, these doctors were not prepared to identify the multitude of symptoms their patients exhibited and were unable to apply the information that they had previously memorized. Thus, McMaster developed a program where the students would use a tutorial process because students learn best by doing and thinking through problems (Delisle, 1997). This process consisted of a sequence of steps used in problem-based, self-directed learning using deductive reasoning (Barrows, 1988). It was used by physicians to help recognize
problems that patients came to them with, in hypothetical situations. This process of PBL developed the students' abilities to extend and improve knowledge and how to provide care for new illnesses they encountered.

Although, first developed for the medical school setting the tutorial process as described by Barrows has now been adopted and used in all levels of education. From grades kindergarten through 12th grade, PBL has been implemented in a number of school settings and content areas. Thus, implementing PBL into the curriculum provides all students the opportunity to develop basic problem-solving and critical thinking skills for the future.

What is Problem Based Learning?

According to Delisle (1997) PBL provides students with the opportunity to discover which leads to greater comprehension of the content by enabling students to personalize their learning. It is a focused hands-on approach to the subject matter. Kendler and Grove define PBL as, “a pedagogical approach to learning that involves the presentation of a curriculum-related problem or situation whose solution requires students to practice skills of analysis, integration, and application” (1997, p. 448). Usually these problems are messy or ill-structured and open-ended. This means that there is no clear-cut answer that jumps out at the learner when first confronting the problematic situation. Students are encouraged to use prior knowledge, research and problem-solving skills to approach the problem. Throughout the process of trying to solve the problem, students are also using critical thinking while become engaged through hands-on and minds-on learning.
When developing a PBL for the classroom, teachers use real-life scenarios and situations that are occurring. Throughout life, there will always be situations that present themselves as problematic. These situations can be the basis of a PBL. The scenario that students are presented with can be fictitious, but it has the potential of actually happening within the community and student’s lives.

Once students are given the ill-structured situation, they must assume roles of the stakeholder (Torp & Sage, 2000). Taking on this stakeholder role allows students to also take ownership over the situation. The students identify the problem and learn whatever is necessary to arrive at a viable solution.

Through this process the teacher plays a very important role. The teacher acts more like a coach or facilitator, who guides student learning. Rather than being the main source of information like in lecture-based learning, the teacher provides guidance and uses probing questions to motivate student thinking and guide student inquiry. The teacher creates a learning environment to facilitate deeper levels of understanding (Torp & Sage, 2002). As a facilitator, the teacher makes suggestions about the problematic situation when students get stuck.

Why Use PBL?

Experience is the best teacher. Through PBL students learn by doing and providing experience for the students. According to Harlen (2002), students build up concepts that help them link their experiences together and develop an understanding of the world around them. “The learning that is generated by this approach is more meaningful to students and is better retained. The knowledge becomes a part of their
experience" (Benedis-Grab, 2006, p. 21). Educators are implementing PBL more and more in their classrooms because of the skills that it helps students develop as well as the knowledge that is acquired through the process. "Advocates for PBL claim that it has the potential to promote student understanding of discipline-specific knowledge; foster the development of a range of skills such as problem solving, critical thinking, collaborative learning and self-monitoring skills; and enhance student motivation" (Goodnough, 2005, p. 88). PBL enables students to become open-minded, complex thinkers and leaders who are able to assess the world around them.

Barrows (1998) also writes that students reflect on their thinking, or using the process of metacognition.

Metacognition is this executive function in thinking: pondering, deliberating, or reflecting on the problem or situation; reviewing what is known and remembered about the kind of problem confronted; creating hypotheses; making decisions about what observations, questions or probes need to be made; questioning the meaning of new information obtained from inquiry; pondering about other sources of information; reflecting on and reviewing what has been learned, what it all may mean and what needs to be done. (p. 3)

In other words, students are constantly thinking about their thinking. This is done through a reiterative process of inquiry.

The Thayer Model represents an example of this reiterative process. It is a four step problem-solving cycle, which allows students to identify and solve problems. Using science, math and technology students define a problem, describe specifications, determine a solution, and redefine the problem, which begins a new cycle (Fray, 2006).
The Thayer model is very useful because it “teaches students an authentic problem-solving model that works with real problems” (p. 47) inside and outside of the classroom.

Again, PBL helps to build and develop skills essential to everyday life. Through collaboration with others, students develop communication and social skills while working through the problem in which they were presented. When first approached by the problematic situation, students brainstorm, question and formulate ideas and hypothesize with their peers. Students will then research the problem and conduct investigations; then gather, analyze and make conclusions about the information that they have collected to come to a reasonable conclusion, using problem-solving and critical thinking skills.

In a comparison of Lecture-Based Instruction (LBI) and PBL, Ward and Lee (1996) found that students from the PBL group showed a greater understanding of the connections between content. Both groups of students were introduced to a semester long food and nutrition class as required by the North Carolina Standards. The LBI group received the content through lectures, readings and worksheets, as well as food preparation labs. Initially, the PBL group was presented with situations at the beginning of each unit. Each scenario was a real-life issue that had no right answer and thus required students to utilize critical thinking skills. The PBL students needed to research nutritional value, storage requirements and relevant preparation techniques of their chosen fruit. Students then had to find and prepare recipes using their particular fruit and conduct taste tests. Although PBL was found to be as effective as LBI in facilitating students' attainment of food and nutrition, Ward and Lee found that the PBL students demonstrated improved critical thinking skills compared to the LBI students.
Due to the nature of PBL, students become engaged with the content. They want to solve the problem using a reasonable solution, not simply for the grade, but for the hands-on, real-life experience that it provides the students.

**Implementing PBL in the Classroom**

Before becoming a facilitator, the teacher must first design the PBL and decide what content needs to be covered. Then the teacher writes a preliminary problem statement. The teacher should develop the problem based on knowledge of her students. She needs to take into account the needs of individual students, values, interests, experiences, feelings, culture and backgrounds along with correlating the curriculum standards (Delisle, 1997; Sage & Torp, 2002). Delisle says that “when PBL problems touch students’ experiences and interests, students will be more actively involved and work harder at solving them” (p. 16). The inspiration for a PBL unit can come from any number of sources. Materials can be found in magazine or journal articles, newspaper articles, television, legal cases, or textbooks.

Teachers should design the PBL to engage or hook the students. When students first encounter the problem, they take on roles as stakeholders in the scenario. This can be done in a number of ways. Torp and Sage (2002) suggest giving students an authentic letter or document that describes their role in the problem or enlisting someone such as the principal to describe the problem.

As the class works on the problem scenario the teacher has developed, the teacher must now assume the role of a guide. The teacher sets the classroom environment, helps students to make connections with the problem and guides student learning. Teachers
who implement PBL often find it difficult to guide students without leading and directing (Delisle, 1997). As students research a problem to solve, teachers' offer suggestions and propose alternatives when students seem stuck in their thinking.

The Role of Inquiry

Inquiry plays a very important role in PBL. Inquiry goes hand-in-hand with PBL. These two teaching strategies complement each other very well. "Inquiry is a personal and professional journey that starts with developing a constructivist-based philosophy and reflecting, both individually and with others, on your instructional beliefs and practices" (Llewellyn, 2005, p. xi). Constructivism in the classroom is using a hands-on approach to the content. Students also reflect on their thinking, or use the process of metacognition. The goals of inquiry and constructivism are to develop deeper levels of understanding of scientific ideas (Shields, 2006).

Scientific inquiry focuses on the engagement of students. In inquiry-based learning, students act as investigators to design experiments and answer proposed questions (Llewellyn, 2005). Thus, through inquiry, students are gathering information, analyzing data, interpreting data and proposing explanations for their findings. Initially, investigations come from questions generated by the students themselves or the teacher. Throughout the inquiry, "teachers continually question students to find out what they know and to challenge them to think" (Shields, 2006, p. 6). Teachers act as a guide for the students, never providing them with answers but continuing to probe the students to go farther with their investigations. The teacher continues to act as a facilitator, by
asking questions about procedures guiding students to resources and serving as a sounding board for explanations (Hackett, 1998).

Such questions need to simulate the learner to take a closer look. “The right question asks students to show rather than say the answer and stimulate productive student activity” (Andersen, 1999, p. 48) as well. There are many different kinds of questions that can be asked ranging from concrete to abstract questions.

Harlen (2001) classified these types of questions into 6 different categories ranging from concrete to very abstract. These types of questions include: Attention-Focusing, Measuring and Counting, Comparison, Action, Problem-Posing, as well as How and Why. Andersen (1999) suggests proceeding from concrete questions to abstract questions because it engages more students in learning.

Benedis-Grab (2006) implemented his own inquiry based lesson titled sinking and floating. He approached the term of density with his 6th graders using a hands-on method. In the activity, students collected various materials, then discussed and tested whether each object floated or sank in water. Through their hands on experiments, students gained an understanding of density. “By initiating and conducting hands-on inquiry, students were able to gain a more powerful understanding of the content presented” (p. 19).

PBL in the Science Classroom

PBL can be incorporated into several units in the science curriculum from kindergarten up through college level. Implementing PBL not only allows teachers to
address the content in hands-on, engaging ways, but also enables teachers to meet and
address objectives and standards set forth by the school district and state.

Kendler and Grove (2004) discussed how they introduced a PBL in the college
setting. Two Biology classes experienced different PBL sessions. The first group of
students was taking an introductory Biology course for non-majors. They were
presented with a case of the dying Kudu, a species of antelope that were mysteriously
dying. The objective was to explain what caused the kudu to die of malnutrition. The
students were given time to read the problem and ask questions about vocabulary that
they did not know. Throughout the class, students were able to ask the instructor
questions regarding the problem, but the students themselves would have to explain what
caus ed the antelope to die. Kendler and Grove transcribed the conversation between the
instructor and the students. Throughout the session the students were able to come to a
conclusion on their own.

The second group of students were senior-level Biology majors, who were
presented with a two-week case study about habitat preservation. At the conclusion of
the two-week period students were required to come to a consensus recommendation of
what to do. Students needed to work together and use resources to solve the problem
they were presented with.

At the conclusion both groups of students were surveyed about what they liked
and didn’t like about the PBL sessions. Comments about what students liked are listed
below.

They were challenging and involved us to inquire further to get answers. It gave
us a chance to actively participate in discussion, which I feel is important. [I]
learned how to constructively think out a problem, weigh both sides, [and] devise a game plan. Gave students an opportunity to think about and discuss problems in an open forum environment. [It] improved problem-solving skills and group decision making. (p. 353)

When asked what they did not like about the sessions, students responded with: “Nothing. There was not enough preliminary information given to us. I didn’t like the fact that we didn’t find out what the real outcome was for the conservation topic. Some things aren’t as easy to prove as you might hope or think” (p. 354).

Jack Tessier (2004) also found similar positive results with his PBL concerning environmental issues. He developed a PBL to engage his students using a fictitious scenario about the town wanting to sell a nearby park. Students were asked to take on a stakeholder role to assess and determine ecological repercussions if the land were to be sold. Students actually went out into the field to collect data during the designated laboratory period. Throughout the PBL, Tessier provided his students with guidance and suggestions when students got stuck. He did not, however, lead or direct his students through their exploration and inquiry of the PBL. After testing the soil in the area for minerals and microorganisms, the students concluded that a portion of the park was of great ecological value and that it should not be sold. This section of land, according to the students, had the greatest species diversity with regards to trees, saplings, understory plants, as well as the rarest tree species and the cleanest water. When students were asked to anonymously evaluate the PBL, students wrote, “that it was a valuable experience and provided important hands on insight” (p. 483). One student felt that “this class has really opened my eyes to ecological issues” (p. 483) and also stated, “I was not
very interested in ecology before I started, but now have really come to appreciate it” (p. 483). Two students felt that they could have used more guidance through the PBL.

Stuart Birnbaum (2004) writes how typically disengaged students became engaged with the material when given a hands-on PBL. His research took place in an urban setting where settings were not ideal to getting students engaged with the subject matter, due to lack of resources and money. A field-based collaborative Earth systems inquiry was set up with the Department of Earth and Environmental Science at the University of San Antonio and the South San Antonio Independent School District.

Previous to the collaboration, “hands-on activities were important components in the curriculum, but they were conducted out of context, with no clear link” (p. 407). Birnbaum indicated that because these students were in the urban setting, they were not exposed to the Earth in way that helped them connect with the material that was being taught. In an effort to make science relevant to real-life, a PBL was implemented.

While out in the field students were able to discover some of what the Earth had to offer. They found large rocks, which were home to scorpions living underneath. Students were then asked to address the following questions about the scorpions: “Are scorpions associated with specific soil types? If so, what soil properties control the association? Do scorpions spend all their time under rocks or do they leave for food? If they leave, do they return to the same rock” (p. 409)? Students observed and hypothesized how the scorpions could survive living under the rocks by recording temperature and soil moisture. They also collect soil samples and analyzed grain size, water retention capacity, density, color and composition.
The following qualitative data was collected. One teacher said, "The students were engaged, they asked intelligent and pertinent questions" (p. 409). Another said that, "some students were so excited that they even wanted a chance to work on their projects during the summer" (p. 409). One student that was surveyed said, "I want to keep investigating rocks and how many types of rocks there are in the whole world? Also I want to see if I can make a sandstone myself and also erode a rock and see how fast they erode and what shape they come out" (p. 409).

Susan Groenke and Randall Puckett (2006) implemented a different type of PBL in their 11th grade classroom. They used a PBL strategy called a RAFT. Each letter of the RAFT has its own meaning. R is for role; the writer needs to decide what she will be writing as. Next is A for audience. The writer needs to write to a specific audience. The writer must also pick a format to write from and how it will be set up. This is the F part of the RAFT. Lastly, the T stands for topic. The writer needs to choose what she will be writing about.

The goal of this particular RAFT was to engage 11th grade students and to become environmentally literate citizens. "According to the North American Association of Environmental Education (NAAEE), environmentally literate citizens understand that the interrelated, dynamic systems we create - our societies, political systems, economies, religions, cultures and technologies - affect the total environment" (Groenke & Puckett, 2006, p. 24) To accomplish this, the RAFT writing strategy was used. It helped students to make connections between prior knowledge and new concepts while encouraging creativity.
Specifically, Groenke and Puckett employed a RAFT on the topic of wetland and farmland development for retail use. They facilitated student thinking about the interconnections of humans and the environment by allowing students to view different perspectives on the situation.

Using a rubric (a grading tool) to access each RAFT, Groenke and Puckett felt that the students were successful. The strategy helped students to develop literacy skills while making meaning of the content.

Eisenkraft, Heltzel, Johnson and Radcliffe (2006) used a PBL to link art and chemistry together. Basically, chemistry students create an original artwork while describing the chemistry principles behind their artwork. This 5-week PBL unit centers on the Artist as Chemist. Students are challenged to create a piece of art that represents themselves.

Students learned chemistry through a series of eight activities and then discussions took place about the changes that occurred. The title of each category were as follows: What is Art?, Choice of media for durability, Chemical behavior of metals, Physical behavior of metals, Clay, Paints, Dyes and lastly, Glazes and glass. “Students are encouraged to view all chemical interactions from the observable properties of material substances before and after the reaction and the atomic level explanation of what is occurring” (p. 34). Thus, students are learning about structures, formulas, equations, math, models, diagrams and graphs.

Another common use of PBL in the science classroom is during a genetics unit. Five mentor teachers from the New York State Biology–Chemistry Professional Development Network developed a PBL curriculum module focusing on the implications
of genetic testing (Markowitz, DuPre, Holt, Chen & Wischnowski, 2006). In the PBL, the students are presented with the following scenario:

Jenny is a teenager facing a critical decision. Should she have DNA testing for Huntington’s disease (HD), a genetic disease that took the life of her grandmother? Why does her mother insist that Jenny get tested? Why won’t her father get tested when he’s started to show symptoms of HD? What are the potential consequences of this decision for Jenny and for her family? (p. 29)

Once encountering the problem, students then work in teams to arrive at solutions to this real-life problem.

While researching HD, organizing and analyzing data, students also learn about basic ethical values. Students come across issues of confidentiality, privacy, honesty, fidelity and integrity. Teams must then weigh the risks, benefits and consequences of each course of action. Using an agarose gel, students perform gel electrophoresis using simulated DNA samples from Jenny, her father and her brother. Students then analyzed the results and prepared a laboratory report just as a genetic counselor would use.

Upon implementing this PBL into their curriculum, teachers found that their students were engaged, enjoyed role-playing and were motivated throughout the unit. One teacher said, “They asked more meaningful questions than when we use different learning and teaching methods” (p. 32). Teachers also noted that students who hadn’t shown much interest in science before were engaged. Many teachers commented that, “students enjoyed the hands-on lab the most and couldn’t wait to find out who had the gene” (p.32).
Duncan and Daly-Engel (2006) also implemented a PBL during their genetics unit based on the hit television show, *CSI* (Crime Scene Investigators). Prior to any activities, students became familiar with false-positive tests, lab protocols, glove-use practices, pipetting techniques and ethical issues related to science in criminal investigations.

Students began the unit with investigating blood-typing lesson. Students visualize a simulation of the reaction between antibodies and antigens in blood through a reaction of milk protein and vinegar. The problem scenario that students were presented with was three same sex babies were mixed up during a hospital fire. Students then had to figure out whom each baby belonged to using pedigrees and Punnett squares. Then students were presented a scenario of a stolen prized parakeet. They needed to use Restriction Fragment Length Polymorphisms (RFLP) and gel electrophoresis to match the suspects with the evidence. Once students collected all the evidence from the crime scene and analyzed it, they needed to write up a formal report, revealing their findings.

Throughout the forensics unit, students were assessed on the following skills and concepts: safety, blood typing and Punnett squares, DNA extraction, measurement and use of laboratory equipment, RFLP, Polymerase Chain Reaction, DNA sequencing and fingerprinting and finally electrophoresis. When students were given the opportunity to see forensics in the real-world, they were intrigued. “During our field trip to the marine molecular facility, students were more excited to observe a skilled scientist rapidly pipetting DNA into a large gel than they were to feed captive sharks” (p. 41).

Throughout the entire unit, students were excited and engaged in solving crimes that their teachers had created. Duncan and Daly-Engel felt that using the forensics unit was an effective way to engage the students in topics that would be covered anyway.
Quitadamo and Campanella (2005) felt that the community provided an excellent place for scientific study of native animals. They decided to implement a PBL which compared the local cougar’s habitat and behavior before, during and after resort development.

Students were confronted with the following ill-structured problematic scenario that was currently happening in their own community.

What happens when cougars—who need individual ranges up to 160 km² for their survival—are confronted with a booming human population? Where do North American’s largest native cats go when their habitat gives way to hundreds of new houses?

We need a plan, one based on your own knowledge of genetics and biodiversity. In the next few weeks, you will be learning about DNA, heredity, genetic variability, and much more. You will put your knowledge and research skills to the test by making a Cougar Conservation Plan for the Cle-Elum area.

The current population of cougars has been dramatically reduced in numbers, something that is called a bottleneck. We need to work fast and come up with a plan to help the cougar population regain numbers. Your job is to come up with a genetic plan of attack. You will research, write and present your plan that is worth 100 points toward your grade and will possibly be submitted to WDWF biologists. Good luck. (p. 29)

Throughout the Cougar Conservation Project (CCP) PBL, it was noted that student engagement participation, time on task, focus and interest all improved. “It is reasonable to suggest that the process of solving an authentic problem facing the
community, working in small collaborative teams, and providing an interdisciplinary context effectively engaged students” (p. 31). This PBL provided students with a meaningful problem scenario that was relevant to their own lives.

PBL is a teaching strategy that has become useful in the classroom setting. Students gain a deeper level of understanding with the material while being more engaged with it as well. The nature of PBL allows students to take ownership of their learning because they become stakeholders in an authentic situation. Students use higher-level thinking skills to come to a viable solution to the problematic scenario. Thus, the literature review suggests that teachers should start moving away from lecture-based lessons and more towards PBL, where inquiry and hands-on exploration promote student engagement with the content.
Methodology

Throughout the 2006-2007 school year, the curriculum for General Chemistry, 8th Grade Science and Regents Living Environment was approached using both PBL and non-PBL lessons. PBL lessons in conjunction with inquiry-based lessons were implemented throughout the units of Matter, Energy, Ecology, and Cells.

Participants

Participants in this study were in grades 8-12 in the Rochester City School District. Four classes in the Bioscience and Health Careers School at Franklin were introduced to PBL lessons throughout the school year. Using the appropriate curriculum for each class, students experienced PBL.

There were a total of 98 registered students for the four classes. Among the population of those 98 students 64% were African American, 20% Hispanic, 14% Caucasian and 2% were of other ethnic background. Eighty percent of students qualified for Title I services due to the fact that the family income was below the poverty level.

Participants in the General Chemistry class consisted of a mixture of 10th-12th graders. The class roster consisted of 14 students scheduled for the class, 4 male and 12 female. However, only 7 students were consistently present throughout the year.

In the 8th grade science class the majority of participants were female, 16 to 4. The class roster consisted of 20 students, although, 15 were present on a regular basis.

The final two classes were both Regents Living Environment. For the purpose of this study, the first class will be called L.E. group A and the other class L.E. group B.
Group A consisted of 11 males and 22 females. Throughout the course of the 2006-2007 school year, however, students were consistently absent or placed elsewhere. Therefore, the exact number of participants fluctuated throughout the study.

Much like group A, the number of participants in L.E. group B, fluctuated for the same reasons. At the start of the school year 13 males and 16 females were scheduled for the class.

**Materials**

Throughout the study, qualitative tools were used to measure student engagement with the content.

The primary source for gathering data was through teacher observations of the students throughout the year. As students encountered PBL lessons, engagement with the material was noted. Unprompted discussions with the teacher as well as between the students were also used as part of the data collection. The observations made during the PBL lessons were then compared to previous non-PBL lessons through the process of teacher reflections.

The second source for gathering data for the study was through student reflections. Students were asked to reflect on their experiences at various times throughout the school year. Students were asked to reflect on their experience with the PBL lessons. Reflections also consisted of general likes and dislikes that the students had encountered with the subject area.

The final tools for gathering data were through observations made by the mentor of the classroom teacher. He noted student engagement with the material and classroom
discussions regarding the PBL lesson. CFU which is short for Check for Understandings, were used as well. These CFU’s were used as checkpoints to see where student understanding and knowledge of the content was.

*Design and Procedure*

Throughout the 2006 – 2007 school year students in the four classes were introduced to a variety PBL lessons. Both the chemistry and 8th grade science classes covered a matter and energy unit. Within in this unit, students were asked to write a RAFT, which is a creative story that exemplifies student’s knowledge of the content. Students were to pick a role to write from and discuss the three states of matter (Appendix A). Also in this unit, students investigated combustion of a candle through hands-on experimentation. Appendix B is the PBL assignment the General Chemistry students were given and the 8th graders were given the PBL in Appendix C. Through experimentation, students were asked to figure out what happens to the wax in a burning candle.

A PBL was implemented with the General Chemistry class regarding density. Using an inquiry approach, students experimented with sinking and floating. Students needed to conduct tests using diet and regular soda (Appendix D).

During a lesson on chemical changes, the General Chemistry experimented with catalysts. Students investigated the breakdown of hydrogen peroxide, the reaction that occurred and made suggestions how and why it was a chemical change that was occurring. Students were able to use an inquiry approach to answer such questions. In another PBL, the class encountered a forensics problem. The General Chemistry class
was asked to identify a murderer by testing and investigating evidence left behind at the crime scene. Students used techniques such as paper chromatography, fingerprint analysis and gel electrophoresis results to identify the culprit.

Within the ecology unit, both Living Environment classes encountered a two week PBL. Students were asked to investigate the effects of non-living factors on radish seeds (Appendix E).

Students in the Living Environment classes experimented with eggs in the egg osmosis inquiry PBL (Appendix F). Students chose what fluids to use to demonstrate how osmosis works through a semi-permeable cell membrane.

The Science 8 students were asked to activate their prior knowledge when they encountered the sink versus float PBL (Appendix H). Students were asked to predict whether their items would sink or float. Students were asked to analyze their data to see if they noticed a trend among their items.
Results

A triangulation of data was used to determine engagement of the students during PBL and non-PBL lessons. Through the use of student reflections, classroom observations, teacher reflections and classroom discussions, PBL lessons were met with great enthusiasm and student engagement.

Throughout the course of the 2006-2007 school year, students encountered PBL lessons. In Tables 1, 2, 3 and 4, students were asked to reflect on their experiences. The information from the student reflections was collected three months after the start of the school year. Students were asked to reflect on four questions. These questions consisted of which lessons or activities did the students like the most and learn the most from. As well as, which lesson did the students not like at all and which one the students felt that they did not learn from. Within each table, students who did not write anything under the reflection are represented by an N/A. Other students whom did not clearly identify a lesson or wrote none as an answer are represented by none in the table. The table also lists non-PBL activities. These non-PBL lessons encompass traditional lecture-based and note-taking lessons as well as straightforward, non-problem solving activities.

In the General Chemistry class, students were asked to complete five different PBL lessons and activities. Table 1 represents student reflections after completing four of the five PBL lessons. Seven students reflected on their experiences. Four of the seven students felt that the lesson they were most engaged in and liked the most was a PBL lesson. Three students specifically mentioned that they learned the most from a PBL lesson. None of the seven students stated that they disliked one of the PBL lessons. However, two students felt that they did not benefit from writing the RAFT.
<table>
<thead>
<tr>
<th>Student</th>
<th>Most Liked Lesson</th>
<th>Lesson Most Beneficial to Learning</th>
<th>Most Disliked Lesson</th>
<th>Lesson Least Beneficial to Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student A</td>
<td>All</td>
<td>All</td>
<td>None</td>
<td>N/A</td>
</tr>
<tr>
<td>Student B</td>
<td>PBL Chemical Changes</td>
<td>PBL Soda Density</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Student C</td>
<td>PBL Combustion</td>
<td>Non-PBL</td>
<td>None</td>
<td>PBL RAFT</td>
</tr>
<tr>
<td>Student D</td>
<td>PBL RAFT</td>
<td>PBL Soda Density</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Student E</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Student F</td>
<td>PBL Combustion</td>
<td>None</td>
<td>N/A</td>
<td>None</td>
</tr>
<tr>
<td>Student G</td>
<td>PBL Combustion</td>
<td>PBL Combustion</td>
<td>Non-PBL</td>
<td>PBL RAFT</td>
</tr>
</tbody>
</table>
The General Chemistry class was asked to complete a RAFT assignment (Appendix A). Twelve students were given the assignment. Six of the 12 completed and handed in the assignment. Of those six students, all passed with an 81% or better. Ten students participated in the candle combustion PBL activity (Appendix B). Students were asked to write and complete a laboratory report; nine of the 10 students completed the laboratory report, all of which received a passing grade. Three of the nine students received a grade of 80% or better on their report. Ten students participated in the soda density activity (Appendix D). Of those 10 students, seven received an 85% or higher on the required assignment.

Fourteen students in the Science 8 class completed the reflection. Only five of the 14 students felt that a PBL lesson was their favorite activity. Nine students enjoyed a non-PBL lesson as their favorite. None of the students felt that they learned the most from a PBL lesson. Three students felt that the RAFT activity did not benefit their learning and one student did not like the assignment at all. Three other students specifically named non-PBL activities as not benefiting their learning.

Of the three PBL activities the Science 8 class was given, the sink/float activity (Appendix H) was met with the best results. Fourteen students participated in the activity and all 14 students completed the required assignment. Eleven of those students received a 100% on the sink/float assignment. The first PBL the Science 8 students encountered was the RAFT (Appendix A). Sixteen students were given the assignment. Nine of the students completed the RAFT and all nine students passed based on the grading rubric. Eleven students participated in the candle combustion PBL (Appendix C). Nine students
Table 2

<table>
<thead>
<tr>
<th>Student</th>
<th>Most Liked Lesson</th>
<th>Lesson Most Beneficial to Learning</th>
<th>Most Disliked Lesson</th>
<th>Lesson Least Beneficial to Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student A</td>
<td>PBL Combustion</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student B</td>
<td>PBL Combustion</td>
<td>N/A</td>
<td>Non-PBL</td>
<td>N/A</td>
</tr>
<tr>
<td>Student C</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>PBL RAFT</td>
</tr>
<tr>
<td>Student D</td>
<td>PBL Combustion</td>
<td>Non-PBL</td>
<td>None</td>
<td>PBL RAFT</td>
</tr>
<tr>
<td>Student E</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>PBL RAFT</td>
</tr>
<tr>
<td>Student F</td>
<td>Non-PBL</td>
<td>N/A</td>
<td>Non-PBL</td>
<td>N/A</td>
</tr>
<tr>
<td>Student G</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>None</td>
</tr>
<tr>
<td>Student H</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student I</td>
<td>PBL Combustion</td>
<td>Non-PBL</td>
<td>N/A</td>
<td>None</td>
</tr>
<tr>
<td>Student J</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Student K</td>
<td>Non-PBL</td>
<td>All</td>
<td>Non-PBL</td>
<td>None</td>
</tr>
<tr>
<td>Student L</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Student M</td>
<td>PBL Combustion</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student N</td>
<td>Non-PBL</td>
<td>N/A</td>
<td>Non-PBL</td>
<td>N/A</td>
</tr>
</tbody>
</table>
completed the required assignment and received a passing grade. Six of those students received a 100% on the assignment.

Table 3 represents data collected from L.E. group A reflections. Nineteen students took part in the reflection. Of those 19 students, seven specifically named a PBL as their most liked lesson. Only two of those students felt as though a PBL lesson was beneficial to their learning, 10 students specifically felt that a non-PBL lesson most benefited their learning. When considering which lesson students did not like, five students named a PBL and all five chose the radish seed experiment. Ten students chose not to answer which lesson was least beneficial to their learning and only one student stated a PBL lesson.

Both Living Environment classes encountered the same PBL lessons throughout the year. In the L.E. group A class, 23 students participated in the radish seed experiment (Appendix E). Of the 23 students, 18 completed the required laboratory report with a passing grade. Eighteen students participated in the radish seed experiment in L.E. group B. Ten of the eighteen also completed the laboratory report with a passing grade. The second PBL which both groups participated in was the egg osmosis inquiry (Appendix F). Twenty-five students participated and 15 completed the laboratory report with a passing grade in L.E. group A. Twelve of the 15 students received a 100% on the laboratory report. In the L.E. group B class, seven of the 17 students that participated completed a laboratory report. All seven of the students received a passing grade and four students actually received a 100% on the assignment. Seven students in the L.E. group A class, experimented with yeast, in the laboratory, is yeast alive? (Appendix G). All seven students completed the required laboratory report with an 83% or higher. In
Table 3
*L.E. group A Reflection*

<table>
<thead>
<tr>
<th>Student</th>
<th>Most Liked Lesson</th>
<th>Lesson Most Beneficial to Learning</th>
<th>Most Disliked Lesson</th>
<th>Lesson Least Beneficial to Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student A</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>PBL Radish Seed</td>
<td>None</td>
</tr>
<tr>
<td>Student B</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student C</td>
<td>PBL Radish Seed</td>
<td>Non-PBL</td>
<td>All</td>
<td>N/A</td>
</tr>
<tr>
<td>Student D</td>
<td>Non-PBL</td>
<td>N/A</td>
<td>Non-PBL</td>
<td>N/A</td>
</tr>
<tr>
<td>Student E</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Student F</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student G</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>PBL Radish Seed</td>
<td>PBL Radish Seed</td>
</tr>
<tr>
<td>Student H</td>
<td>Non-PBL</td>
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<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Student I</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>PBL Radish Seed</td>
<td>N/A</td>
</tr>
<tr>
<td>Student J</td>
<td>PBL Radish Seed</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student K</td>
<td>Non-PBL</td>
<td>N/A</td>
<td>PBL Radish Seed</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student L</td>
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<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
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<td>Non-PBL</td>
<td>Non-PBL</td>
<td>PBL Radish Seed</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student N</td>
<td>PBL Radish Seed</td>
<td>All</td>
<td>Non-PBL</td>
<td>N/A</td>
</tr>
<tr>
<td>Student O</td>
<td>PBL Radish Seed</td>
<td>N/A</td>
<td>Non-PBL</td>
<td>N/A</td>
</tr>
<tr>
<td>Student</td>
<td>PBL</td>
<td>Non-PBL</td>
<td>PBL</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>---------</td>
<td>-----</td>
<td>---------</td>
<td>-----</td>
<td>---------</td>
</tr>
<tr>
<td>Student P</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student Q</td>
<td>PBL Radish Seed</td>
<td>PBL Radish Seed</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student R</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>All</td>
<td>N/A</td>
</tr>
<tr>
<td>Student S</td>
<td>PBL Radish Seed</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
the L.E. group B class, five students participated and four of the students completed the laboratory report. All four students received a passing grade of a 98% or better.

Students were asked to again reflect on their classroom experiences half-way through the 2006-2007 school year. Figure 1, shows which lesson/activity students in the Science 8 class liked the most. Nine of the 13 students, or 69%, named a non-PBL as their favorite activity. Only 31% of the class specifically mentioned at least one PBL lesson. In Figure 2, eight students in the L.E. group A class named one of the PBL lessons as their favorite activity. Four students, or 22%, chose a non-PBL lesson as their favorite and six students did not answer. L.E. group B results are found in Figure 3. Seventy-five percent of the students named at least one of the PBL lessons they encountered as their favorite activity. Three students liked a non-PBL lesson the best.
### Table 4
L.E. group B Reflection

<table>
<thead>
<tr>
<th>Student</th>
<th>Most Liked Lesson</th>
<th>Lesson Most Beneficial to Learning</th>
<th>Most Disliked Lesson</th>
<th>Lesson Least Beneficial to Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student A</td>
<td>Non-PBL</td>
<td>N/A</td>
<td>PBL Radish Seed</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student B</td>
<td>Non-PBL</td>
<td>N/A</td>
<td>N/A</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student C</td>
<td>Non-PBL</td>
<td>N/A</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student D</td>
<td>PBL Radish Seed</td>
<td>N/A</td>
<td>Non-PBL</td>
<td>N/A</td>
</tr>
<tr>
<td>Student E</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student F</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>PBL Radish Seed</td>
</tr>
<tr>
<td>Student G</td>
<td>N/A</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student H</td>
<td>Non-PBL</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Student I</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
</tr>
<tr>
<td>Student J</td>
<td>PBL Radish Seed</td>
<td>PBL Radish Seed</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Student K</td>
<td>Non-PBL</td>
<td>Non-PBL</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>
Figure 1
Science 8 Mid-Year Reflection of Favorite Activity

- PBL Lessons: 4 Students, 31%
- Non-PBL Lessons: 9 Students, 69%
Figure 2
L.E. Group A Mid-Year Reflection
of
Favorite Activity

- Did Not Answer
  6 Students
  33%

- PBL Lessons
  8 Students
  45%

- Non-PBL Lessons
  4 Students
  22%
Figure 3
L.E. Group B Mid-Year Reflection
of
Favorite Activity

Non-PBL Lessons
3 Students
25%

PBL Lessons
9 Students
75%
Discussion

According to the review of literature (Delisle, 1997; Torp & Sage, 2002; Kendler & Grove, 2004), students gain a deeper level of understanding with the material while being more engaged when encountering PBL lessons. Through this investigation of PBL in the science classroom, there was an overall positive outcome which aligned with the review of literature.

Students appeared to be more engaged with the PBL lessons than traditional lecture based lessons. In fact, both Living Environment groups of students were eager to see what happened with their radish seeds. Delisle (1997) says that PBL provides students with the opportunity to discover which leads to greater comprehension of the content by enabling students to personalize their learning. This was especially true for the radish seed PBL. Students developed their own hypothesis to test, which dealt with what affects seed growth. They were then challenged to create and develop their own experiment and procedures. One student decided to test the effects of watering the seeds with varying amounts of diet coke, while another decided to test the affects of population density on radish seeds. By allowing students to personalize their own experiment they were given the opportunity to discover questions they had, which led to greater comprehension and engagement. Such engagement was obvious because students would come into class and head straight for their plants. Throughout the Ecology unit, several students even came into the classroom to check on their plants between passing time. This was especially the case for students in L.E. group B, because they had class at the end of the day.
Both groups also gained a deeper understanding of osmosis and permeability through the osmosis egg inquiry. Students were visibly engaged with the hands-on laboratory because they would come in to class and request to observe what the eggs looked like. Students would ask how they could replicate the experiment at home so they could show their parents. Most students were able to explain why eggs were good for investigating the process of osmosis when asked to summarize it and relate to the cells in their body. One student stated that this was the most liked lesson “because I learned a lot.”

Students in the Science 8 class were intrigued with the candle combustion lab. They intently watched as the teacher relit a candle without touching the wick. Students hurriedly approached the front lab table to get a better look. Students were excited and eager to try it on their own. During the PBL lesson students exclaimed, “This is cool,” and encouraged their classmates to watch them as they investigated the combustion of a candle.

When the Science 8 students participated in the sink versus float PBL, they brought in prior knowledge and experience. Harlen (2001) states that students link their experiences together and develop an understanding of the world around them. Students brought such understanding to class when investigating buoyancy and density during the PBL. Student’s actually uncovered misconceptions they had about items that would sink and float as well. Thus, their new knowledge became part of their experience. This PBL experienced similar results as Benedis-Grab (2006), in that students gained an understanding of density through their hands on experiments.
The literature (Torp & Sage, 2002) suggests that teachers develop fictitious PBL lessons that model real-life to implement in the classroom, just as McMaster University would do for its medical students. Throughout this study, the majority of PBL lessons that were implemented were authentic. The General Chemistry class experienced a PBL that was completely fictitious based on the hit show CSI. Students were excited to know that they were going to solve a crime. Students eagerly put on their “official lab coats” and gloves and opened up the evidence bag while taking on the role of a crime scene investigators. Students then tested and examined the evidence to try and figure out who the culprit was. Students discussed possibilities and even tried to come up with motives about why the crime was committed. In this instance, students were thinking about their own thoughts, as proposed by Barrows (1998). The process of metacognition, had students questioning their own point of view and pondering alternatives to their reasoning. Initially, when the CSI PBL was planned, there was no thought about students discussing motives but the PBL took on a different identity when the students took over. Just as Torp and Sage (2002) suggested, students took ownership of their learning and became motivated to think deeper to come to a viable solution. Students were not sure if they had actually solved a real crime or something their teacher had made up but they were talking about it days afterward.

In the same General Chemistry class, students were asked to investigate the combustion of a candle. Students were able to act as investigators to design their own experiments and answer proposed questions. This constructivist approach proposed by Llewellyn (2005) in the literature was met with great enthusiasm. Student ‘C’ said it was the most liked lesson because, “I had an outline on it and it made it easier for me to
understand and how to do it.” Other student’s stated that they liked the lab because it was very hands on and it allowed students to investigate chemical reactions they never before thought about. As students were performing their experiments, they were visibly engaged. However, some students were noticeably frustrated when the teacher would not give straightforward answers to their questions but instead tried to guide them.

According to Torp and Sage (2002), the teacher should become a facilitator during PBL lessons, and simply guide the students not give answers. A few of the students were so uncomfortable with this type of teaching technique that they withdrew themselves from the laboratory area. They were also frustrated because there was no clear-cut answer that jumped out at them. Tessier (2004) experienced similar results with some of his students who said they could have used more guidelines through the PBL.

When reflecting on their experiences in the classroom, most students who chose a non-PBL lesson as their favorite activity contained food. In the Science 8 class, seven out of nine students who chose a non-PBL activity picked the ice cream making activity. Students said the ice cream activity because, “it was food and we got to eat it.”

Students seemed to have difficulty writing the RAFT and it was frequently listed as the least liked activity for both the Science 8 and General Chemistry class. Students struggled with trying to write it and required several written and verbal examples in the beginning. Similarly to Groenke and Puckett (2006), students were successful even though they struggled with the assignment at first. Extra credit was available to the General Chemistry students if they wrote a RAFT on chemical bonding. A few students decided to complete it and were very creative and did very well on it.
Conclusion

PBL is an outstanding technique to use in the classroom. Students become more engaged with the material when they are able to relate the content to their real-life and experience it hands on.

Planning and implementing a PBL is very time consuming and requires dedication from the teacher. Throughout the study it appeared that students were uncomfortable with some of the PBL lessons because they had never encountered such teaching strategies before. Students would be able to benefit more if they experienced them earlier in their school career. Then, hopefully, students could approach very abstract PBL lessons as Harlen (2002) discussed in the literature. Students in this study encountered PBL lessons that were very concrete rather than abstract.

It was difficult to determine if the PBL always helped the students to have a deeper and better understanding of the content. In the future, classes of the same course should be treated differently. One class would encounter a PBL and the other a traditional lecture based lesson, then there could be a head-to-head comparison of the classes.

Students may also be more engaged with a PBL that deals with food. Students in this study expressed interest in lessons that dealt with food. Therefore, it would make sense to try to implement a PBL with food as long as it aligned with content standards.

The lack of resources in the city school district often impedes a teacher’s ability to implement new and hands-on activities for students. Such was the case in this study. Certain PBL lessons were avoided due to the lack of materials and resources available. Unlike, in Stuart Birnbaum’s (2004) classes there is not a working relationship with area colleges, for urban students to have a better opportunity.
Essentially, students develop a deeper understanding of the topic and are much more engaged when they are able to experiment, observe and analyze their own hands-on activities. Students learn by doing, PBL gives students that experience.
References


Appendix A

Phase Changes RAFT

A RAFT is a creative story you write in which you are able to demonstrate your knowledge of the science content. When you write a RAFT you write from the point of view of a character or object involved with the topic and write to a specific audience.

- **Role**: What will you be?
- **Audience**: Who will be reading/receiving your writing?
- **Format**: How will the writing be set up?
- **Topic**: What will you be writing about?

For this RAFT you may choose any role, audience, format or topic you want, but keep in mind the story must show your knowledge of phase changes. Your story must explain:

- How particle motion is changed
- How the arrangement of particles is changed
- How the phase is changed with increasing temperature

*Your story must start at -10°C and go through to 120°C

You will receive extra credit for including pictures. If you are stuck, there are some ideas listed below. Feel free to use them or modify them.

<table>
<thead>
<tr>
<th>Role</th>
<th>Audience</th>
<th>Format</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Grandpa water</td>
<td>Baby water</td>
<td>A bedtime story</td>
<td>The phase changes he has gone through in his life</td>
</tr>
<tr>
<td>molecule</td>
<td>molecule</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A thermometer</td>
<td>Water molecules</td>
<td>A travel brochure</td>
<td>The temperature he shows while they are changing phases</td>
</tr>
<tr>
<td>----------------</td>
<td>----------------</td>
<td>-------------------</td>
<td>------------------------------------------------------</td>
</tr>
<tr>
<td>A molecule in a gas</td>
<td>A molecule in a solid</td>
<td>A housing advertisement</td>
<td>Why they should go through a phase change, how much they would enjoy all the extra space in a gas</td>
</tr>
<tr>
<td>One water molecule</td>
<td>Another water molecule</td>
<td>A love letter</td>
<td>Remembering the old days (when they were so packed together in a solid) and talking about how much he misses the other since they are now a gas and are so far apart.</td>
</tr>
</tbody>
</table>

Your story must include:

1. At least 5 different temperatures (at least one temp from each phase)
2. A description of particle movement for each temperature
3. A description of particle arrangement for each temperature
4. A description of what happens during a phase change

Don't lose sight of your goal. While this assignment can be creative and fun, I will be grading it for science content.
Appendix B

Combustion Lab-Observation of a Candle

Introduction:

You have seen candles burn, perhaps on a birthday cake. But you probably have never considered the burning of a candle from a chemist’s point of view. In this lab, you will investigate the burning of a candle and the products of combustion.

Problem Statement:

1. What happens to the wax in the candle as it burns?
2. What are the products of the combustion of the candle?

Materials:

- Candles
- Matches
- Metal dish
- Beaker
- Tongs
- Goggles
- Limewater Solution

** You may find it necessary to use more materials, please let me know**

Procedure: ~Goggles must be worn~

YOU NEED TO WRITE YOUR OWN PROCEDURE. TELL ME STEP-BY-STEP WHAT YOU DID, EXACTLY HOW YOU DID IT. PLEASE INCLUDE DIAGRAMS & PICTURES OF YOUR SET-UP.
Data:

YOU NEED TO DEVELOP YOUR OWN TABLE TO PUT INFORMATION IN. OBSERVATIONS OF YOUR EXPERIMENT SHOULD ALSO BE RECORDED HERE.

Conclusion:

REFER TO YOUR PROBLEM STATEMENTS. WHAT DID YOU LEARN & FIGURE OUT. USE YOUR DATA FROM ABOVE TO SUPPORT YOUR CONCLUSION.

Extension:

Wearing your safety goggles, please perform the following procedures and answer the questions.

1. Fill the beaker with cold tap water, dry the outside of the beaker and hold it 3 - 5cm above the candle flame.
   a. What do you notice? There is a phase change that is occurring, explain.

2. Pour water into the pan, no more than 1cm deep. With the candle lit, quickly lower the Erlenmeyer flask over the candle so that the mouth of the flask is below the surface of the water. Allow the flask to remain in place for a minute.
   a. What did you observe? Explain why you think this is happening.

Questions: ~Answer in complete sentences~

1. During your experiment, you observed both physical and chemical changes.
   What were they?
2. Do your results indicate that the candle wax burns as a solid liquid, or a vapor? Explain.

3. One requirement for combustion is the presence of a fuel. Interpret your results. Is their "fuel" for your candle? If so, what is it? If not, why does this form of combustion not need any fuel?
Appendix C
It's Not Out Till It's Out

So What's Up?
Observe the changes of state in candle wax

What's Going On?

Make some observations of what you see during the demonstration.

Materials and Safety
1 candle
1 room without any air currents
matches
safety goggles

Watch Out For...

Fire. Please use proper safety procedures while you do your own experimenting.
Remember our safety rules, most importantly, NO FOOLING AROUND. Please wear your goggles while you are experimenting. Try to answer the following questions below.

Questions *Answer all questions in COMPLETE sentences* (on a separate sheet of paper)

1. Is the wax in the candle a solid, liquid or gas?
2. What happens to the wax that is heated just under the wick?
3. Is the smoke that rises from the wick immediately after it is extinguished flammable or inflammable?
4. Why do you think the candle relights even though the match never touches the wick?

5. Will this experiment work if there is no smoke rising from the wick? Why not?
INTRODUCTION: Throughout the unit one and two, we have gathered information about experimental design and how to make measurements in the science classroom. For this lab you will be asked to “pull” together all the information you have learned from both units and from previous science classes. This lab will require you to question & problem-solve.

You may use your notes, each other and any other resources that may help and guide you to understand and solve this problem. I will not give you answers, I am here to assist and guide you.

Recall what we have discussed so far. (Some will be very helpful to you).

➢ Experimental Design
  o Variables
  o Hypothesis
  o Conclusion
  o Data

➢ Measurements
  o Mass using a balance
  o Volume using a ruler
  o Volume using a graduated cylinder

➢ Formulas
Calculated volume = length x width x height (cm³)

Density = m/v

- Calculated = g/mL OR g/cm³

Other helpful facts

- 12 fluid oz (fl oz) = 355 mL

Investigable Question:

Why does diet soda float and regular soda sink?

Density of Coke

C. Ophardt, c. 2003

What is the difference?
Both cans are in water.

Using your knowledge of science, try to answer the investigable question above. Your grade will be based on a poster that you create. It must include the following:

1. A hypothesis
2. A procedure that you used to "solve" this problem
3. Data (measurements you made and observations)
4. A results section with calculations you made
5. A conclusion section (why does it float?)
Appendix E

Radish Seed Experiment

How do abiotic factors affect biotic organisms?

Introduction:

Last week, we briefly experimented with the effects of salt water on radish seeds. We used qualitative (or observations) to conclude that the seeds grew better in fresh water than in water with salt added to it.

Your Job:

You need to design your own experiment and carry it out in class (yeah, lab minutes!) Recall the process of experimental design. You may use the packet that we covered earlier this year to help guide your experiment.

You need to determine how changing one (1) abiotic factor will affect the growth process of the radish seed.

Here are some ideas that you thought of in class:

- Soil (none / different types)
- Water (none / with other things in it)
- Fertilizer (none versus some)
- Sunlight (none)

Next you need to go through the steps of experimental design. Here are some key elements in case you have forgotten.

1. Problem / question
2. Hypothesis
3. Variables (independent and dependent)
4. Control

5. Constants

6. Data (using diagrams, charts and tables)

7. Conclusion (clearly stating your results in terms of your hypothesis)
Appendix F

The Osmosis Egg Inquiry

Purpose:
Students investigate osmosis by designing experiments involving animal cells (chicken eggs).

Topic Vocabulary:
Osmosis, Diffusion, Permeable, Hypertonic, Hypotonic

Introduction:
An unfertilized chicken egg, like the ones sold in the grocery store, is pretty much a large single cell surrounded by a shell. The ovum is the portion known as the yolk. Surrounding the yolk is the potential embryo’s water and food source, known as the albumen. Thus, the albumen is as accessory storage portion of the cell – sort of like the plant cell vacuole. The yolk and the albumen are contained by two membranes that are just inside the shell. The acetic acid of vinegar dissolves the calcium carbonate of an egg shell. What then remains is a large cell contained by inner and outer membranes. The membranes are selectively permeable and allow for osmosis studies.

In this inquiry, the eggs will be put into various solutions and data will be collected over three or four days. Since the membrane is selectively permeable, some solutes will move across and others will not. An egg in a hypertonic solution will lose water and mass. An egg in a hypotonic solution will gain water.

Materials:
- Raw chicken eggs – 4
- Vinegar – enough for all eggs to be submersed
- Containers
- Various solutions
  - Syrup
  - Salt
  - Sugar
  - Soda

Your Task:
To experimentally answer questions concerning chicken eggs and osmosis.

Day 1: Remove the Shells
Place all eggs into a container filled with vinegar. Leave for 24 hours and the shell will dissolve.

Day 2: Design Day
1. Decide on an experimental question
2. Formulate a hypothesis and prediction
3. Collect initial data
4. Set up your experiment

Day 3: Collect Data

Day 4: Collect Data and End Experiment
1. Take final measurements
2. Brainstorm on conclusions. Was your hypothesis supported?

Lab Write-Up
Appendix G

Is Yeast Alive?

To begin to answer the question, "Is yeast alive", you will test whether the grains of yeast have two characteristics of living things -- the ability to grow and the ability to use energy (referred to as metabolism).

Scientific Experiment to Test for Metabolism

We will carry out an indirect test for metabolism. In other words, we will be indirectly testing whether yeast can use energy, which is one of the characteristics of living organisms.

When yeast, humans, and other living organisms use energy, they break down high-energy molecules like sugar to get the energy they need and give off a gas called carbon dioxide as a by-product of this reaction.

We will test whether yeast can metabolize sugar and produce a gas which we will presume is carbon dioxide. Specifically, we will test whether yeast produces a gas when it has sugar available as a food vs. when no sugar is available.

Research Question:

Do yeast use energy and produce a gas when sugar is available?

Hypotheses:

Do you expect yeast to produce a gas when sugar is available? __________

Do you expect yeast to produce a gas when no sugar or other food is available? __________

Explain the reasons for your predictions.
Procedure to Test Your Predictions

1. Set up two test tubes in a test tube rack.

2. Label each tube with a number, 1 & 2. Test tubes 1 will have yeast, sugar and water. Test tubes 2 will have only yeast and water, with no sugar.

3. Fill test tube #1, 2/3 full with warm tap water. Add 1/2 packet of dry yeast a little bit at a time, mixing the yeast in thoroughly before adding more. Mix by putting your hand or thumb over the top of the test tube and shaking.

4. Pour half of the yeast solution into test tube #2. Make sure there is an equal amount in each test tube.

5. Add ½ spoon full of sugar to test tube #1 (you don’t need a lot of sugar). This tube will be your experimental group. Do not add sugar to tube 2.

6. Add warm tap water to each test tube, filling each test tube 4/5 of the way to the top.

7. Cover the opening of each test tube with a balloon to catch any gas that is formed. Using the balloon to seal the end of the tests tube, hold a finger over the end of each test tube and shake it vigorously to thoroughly mix the contents.

8. Observe the test tubes and record your observations carefully in the table on the next page. Then, every 5 minutes for 25 minutes, observe what occurs in the test tubes and any changes in the balloons which cover each test tube, and record your observations.

9. If the yeast grains are capable of metabolism, it will take some time to produce enough carbon dioxide to see the change in the balloons.
Discuss the results you obtained with your group. How do you interpret your results?

Why is it better to have a test tube with yeast, sugar, and water and a test tube with just yeast and water?

When you make bread, if you just mix flour, sugar and water, the dough does not rise, and the bread will be flat and hard. If you include yeast in the bread dough, then the dough rises and the bread is bigger and fluffier. Can you explain how the yeast helps the bread dough to rise?
Appendix H

Sink versus Float

In this activity, you will determine whether an object will sink or float in water. There are several items that we will investigate as a class.

Below is a suggested table that you may choose to use. You may also develop your own if you want, but either way you need to keep track of your findings.

<table>
<thead>
<tr>
<th>Object Characteristics</th>
<th>Prediction (Sink or Float)</th>
<th>Actual Outcome (Sink or Float)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Now let’s test our items!!

*On a separate piece of paper, answer the following and hand in to Ms. Szozda*

- Discuss results and your predictions
- Discuss answers to the following questions
  - What were the weaknesses in your thinking?
  - What did you learn during the activity?
  - What are your new understandings?

**How can we explore sinking and floating further?**

1. Form groups
2. Decide on a question to test
   
i. For example: Does an object’s surface area affect whether it will sink or float?

3. Formulate a hypothesis *(If, then)*
   
i. For example: If an object has more surface area, then it will float.

4. Explore the interactions and characteristics of each of the new items you wish to investigate.
   
i. Plan out how you will test your items

5. Create a short report of your findings which include item characteristics and interactions with the water in the tank.

The format of your report should contain the following:

1. Your question
2. Your hypothesis
3. Your experimental plan with materials
4. Data collected
5. Conclusions / Reactions to your data
6. New questions to investigate