IMPLEMENTATION OF INQUIRY AND PROJECT-BASED LEARNING IN A HIGH SCHOOL CHEMISTRY CLASSROOM: AN ACTION RESEARCH PROJECT

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Abstract This article summarizes one teacher's action research journey in adapting a traditional gas laws chemistry unit into one that utilized inquiry and project-based learning. Data was collected regarding students' understanding of chemistry content as well as their motivation to learn, and key findings were summarized. In comparison to data from a previous year, results suggested that inquiry and project-based learning generally resulted in increased understanding of content and increased motivation for some students.

Keywords: teacher action research, inquiry, project-based learning, chemistry

Introduction

In 2014, my school district began a multi-year, intensive process of training each of its kindergarten through twelfth (K-12) grade teachers in Direct Interactive Instruction (DII), a teaching model that emphasizes a gradual release ("I do," "we do," "you do") and places the teacher at the head of the learning, both literally and figuratively. The DII materials purchased emphasized the research of Klahr and Nigam (2004) to argue that direct instruction increased student understanding and achievement. However, a tension exists between the teacher-centered emphasis of Direct Instruction and the new Michigan Science Standards, which emphasize inquiry and student discovery of knowledge through a more constructivist approach.

In chemistry in particular, my students often struggle to see how what they are learning applies to their own life and can be used on a regular basis. When students fail to see the relevance, they become disengaged in the learning process and put in minimal effort. Although certain chemistry content knowledge may not always feel relevant to students not planning on going into a science field, the skills that students are practicing, including collaboration, communication of complex ideas, and application of critical thinking, are crucial. I saw the need to implement teaching techniques that involve students in these practices in order to motivate them and authentically engage them in science.

The purpose of this action research project was to explore the tension between direct instruction and more student-centered instructional techniques in an attempt to clarify the most effective approach for teaching science. This was accomplished by reviewing the literature and summarizing my experience in adapting a traditional unit to be inquiry and project-based in my own high school chemistry classroom.

The specific questions this action research project sought to answer were as follows:

1. How does implementing an inquiry-based and project-based learning unit affect student understanding of the content?

2. How does implementing an inquiry-based and project-based learning unit affect student motivation and interest in science?

Literature Review

Traditional science education places the teacher at the head of the classroom to instruct on content knowledge while assigning students a passive role. Allen, Duch, and Groh (1996) claim that this arrangement misrepresents the real process of science, which should be grounded in authentic inquiry and the actual practice of science. This structure lacks engagement, authenticity, and relevance for many students (Kolodner, Camp, Crismond, Fasse, Gray, & Holbrook, 2003), leading to boredom and disinterest in science classrooms across the country (Krajcik & Blumenfeld, 2006). Traditional science education especially disadvantages students of color and girls for whom science achievement gaps have been well documented (Buck, Cook, Quigley, & Prince, 2014). Moreover, as presented by Schank and Kozma (2002), our United States science education scores have been consistently mediocre in studies conducted by the Trends in International Mathematics and Science Study, lending evidence to the claim that a traditional model of science education is not working.

Problem-based learning has emerged as an alternative to this problematic traditional structure. Overlapping in many ways with project-based learning and inquiry instruction, Hmelo-Silver (2004) describes problem-based learning as an instructional framework in which students are presented with an authentic, complex question or problem to solve. In contrast to traditional science instruction, in problem-based learning the teacher acts as a facilitator of learning and students may work at their own pace to learn what is necessary to answer their question and then apply their understanding (Hmelo-Silver, 2004). Rather than students gaining content knowledge, problem-based learning places emphasis on the skills and practices of science in action, such as problem-solving and collaboration (Hmelo-Silver, 2004). According to Hmelo-Silver (2004), this leads to the creation of lifelong learners with flexible skills that are crucial for today's information age.

Project-based learning and its cognates have been successfully implemented in many different contexts with positive results. Mahendru and Mahindru (2001) found that problem-based learning that was implemented in a college electrical engineering course increased scores in learning outcomes as compared to traditional lecture while also promoting problem-solving and self-motivation. Similarly, Yadav, Lundeberg, Subedi, and Bunding (2011) described how the switch from lecture to problem-based learning in an undergraduate engineering course led to an increase in learning gains compared to traditional instruction using a pre-test/post-test methodology. Students who were involved in project-based learning in an AP Biology context had similar benefits, including interpreting and applying knowledge, development of positive attitudes, promotion of problem-solving skills, and facilitation of a deeper understanding of issues relevant to them (Nguyen & Siegel, 2015). Through this project, Nguyen and Siegel (2015) reported that students collaborated with one another, persisted through the semester-long project, and were challenged to engage in inquiry and creativity, ultimately leading to an increased interest in science careers. For Kazempour and Amirshokoohi (2013), the inclusion of inquiry-based learning in a teacher education course resulted in deeper conceptual understanding for students and better application of learning. Kazempour and Amirshokoohi (2013) found that students better appreciated the nature of science through their own participation in the process as compared to traditional science education.

However, changing the status quo does come with challenges. As Kazempour and Amirshokoohi (2013) described, in addition to the learning benefits that came along with inquiry learning, students reported feelings of frustration and confusion. Likewise, Albanese and Mitchell (1993) emphasized that the benefits of problem-based learning may be outweighed by challenges such as slow implementation and poorer student test scores on content-driven exams. Kolodner et al. (2003) identified sequencing, science content, and classroom culture as challenges to successful problem-based learning facilitation.

To overcome these challenges, Kolodner et al. (2003) found that creation of collaborative groups and alteration between whole group and small group instruction provided scaffolding to help students feel successful. Ensuring that time was allocated for reflecting and practicing initial inquiry led to gains in learning, and emphasizing the iterative design and redesign process of problem-based learning was also found to be significant. Finally, they established introductory activities and lessons and familiarized students with structures designed to provide them with opportunities to practice the collaborative skills they would need to develop to be successful in more challenging curriculum.

Schmidt (1983) and Allen et al. (1996) also offered recommendations for successful creation of problem-based learning curricula. The step-by-step guide provided by Schmidt (1983) included identification of key terms, definition and analysis of the problem, formulation of learning objectives, collection of information, and finally synthesis of learning. Allen et al. (1996) cited the importance of the learning facilitator, class format, collaborative group structure, and guidance through carefully constructed problems in the creation of problem-based learning curriculum aimed at engaging all learners in science. Specifically, Allen et al. (1996) recommended starting problem-based learning with an authentic problem that is engaging and relevant, open-ended, controversial, and complex.

With the wide body of literature that exists as a reference for teachers looking to make learning in their own classrooms more student-centered, the challenge is not whether or not to begin, but when and how to jump in right in. Many studies have demonstrated the benefits this instructional framework holds for student learners as compared to traditional science education. Although challenges do exist, recommendations for structures and strategies to overcome the limitations are plentiful, and teachers looking to move away from a traditional, teacher-directed classroom structure have only to look to the literature to appreciate the wide variety of inquiry and project-based resources that are available to engage learners in authentic, relevant, and engaging science practices.

Setting

I implemented inquiry and project-based learning over the course of a four-week unit in a tenth grade chemistry classroom. My high school is a medium -sized, rural school in southeastern Michigan with low diversity and middle socioeconomic status. Although the high school is fairly traditional, as a district we are moving toward a more modern approach to education that emphasizes interdisciplinary integration of content and authentic learning grounded in relevant experiences. With this in mind, there is strong support from administrators for teachers who are trying project-based learning and other non-traditional teaching methods.

Methodology

In three classes, each with approximately 32 students, I began this transition by rewriting the unit's 10 learning objectives as questions rather than statements. For example, the daily learning objective "I can describe the direct relationship between temperature and pressure," became "What is the relationship between temperature and pressure?" After rewriting each objective, the next step was to find a phenomenon whose explanation would get at each topic. This chemistry unit included kinetic molecular theory and ended with gas laws, meaning that the phenomenon needed to be a physical change that involved pressure, temperature, and volume. A short video of a train car tanker imploding served to meet this need, and after watching the video students were prompted to brainstorm questions about the variables that could have caused the dramatic change that they witnessed.

For each learning objective that was introduced, students were told that they were receiving a small "piece of the puzzle" and that by the end of the unit they would be able to fully explain the tanker phenomenon. Each learning objective was taught using inquiry: from process-oriented guided inquiry learning activities to modeling instruction to data analysis, students were guided to answer the learning objective question by constructing their own knowledge with one another rather than being instructed directly by the teacher. At the end of each lesson, students took a short online multiple-choice quiz to assess their understanding of that particular learning objective.

The end of the unit culminated in a series of gas laws mini-phenomena that students modeled at a particulate level to relate back to the original tanker phenomenon. They were then challenged to work in small groups to create their own gas laws phenomenon demonstration as a summative assessment that they would be performing for an audience of elementary students who would be visiting our classroom. These demonstrations were preceded by a written proposal in which students described their procedure, the materials and plan for implementing the demonstration, including all safety notes, and a detailed explanation of the science behind their demonstration with a visual model included. In order to participate in the "demo day," students were told that their written proposal had to be officially approved by the teacher, who would be looking to see that they had anticipated and addressed all safety concerns and procedural issues and could thoroughly explain the science in a written report.

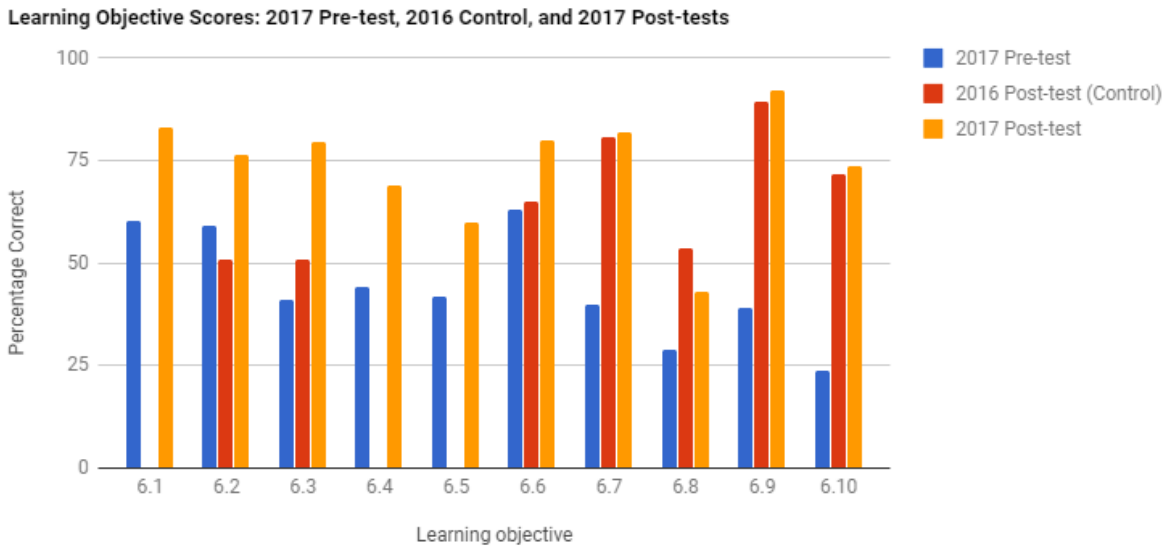
At the start of the unit, students took a pre-test to assess their motivation and initial understanding of the 10 learning objectives before engaging in the inquiry-based lessons and project-based learning final assessment. Across the unit, data was collected to document students' engagement and understanding, including videos of them interacting in small groups, pictures of their models over time, and their scores on the short learning objective quizzes. Because this unit was taught last year with similar learning objectives but a different teaching technique, the scores for students last year and this year's project-based learning unit were able to be compared to objectively document how implementation of these different learning techniques impacted understanding. A post-survey was also administered to assess student motivation and reflect on the unit as a whole.

Confidentiality was the primary ethical concern, and in data analysis, names of participants have been omitted to ensure confidentiality of student participants.

Results

Action Research Question #1. To evaluate the first research question regarding student understanding of the content, average scores for each of the ten learning objectives were calculated across all three classes after the project-based learning unit was implemented. These scores for each learning objective were compared to pre-test scores for the same group of students and the data that was available for similar learning objectives in 2016, and the results are summarized in Figure 1.

Figure 1: Learning objective scores: 2017 Pre-test, 2016 Post-test (used as a control), and 2017 Post-test.

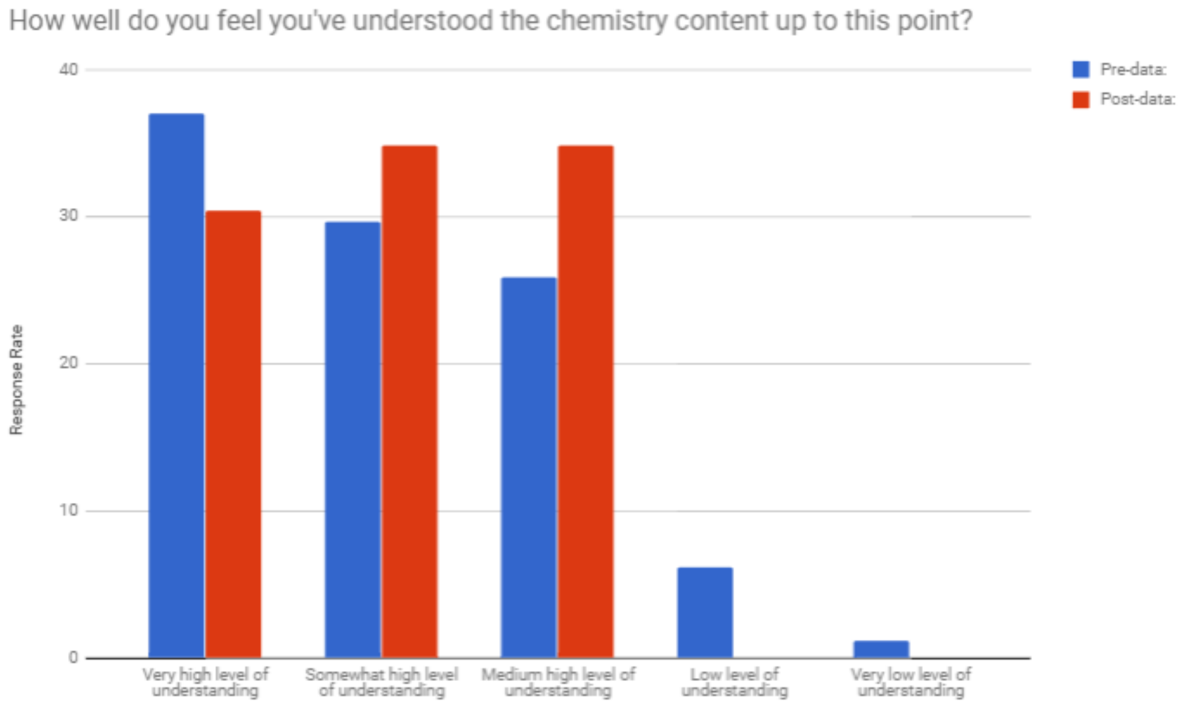


This bar graph shows the average scores for each of the unit's ten learning objectives for the 2017 pre-test, the post-test data available from 2016 students who were taught using traditional methods, and the 2017 post-test after students were taught using project-based learning.

For every learning objective, an increase can be seen in comparing the 2017 students' pre-test and post-test results. For learning objectives other than 6.8, the end-of-unit scores of the 2017 students were higher than those of the 2016 students who were taught using traditional methods instead of project-based learning.

In addition to objective data regarding their understanding, students were also asked to self-assess in a short survey, as shown in Figure 2. Before the implementation of the unit, students were instructed to reflect back on previous units in summarizing their understanding of chemistry content. After the unit, students were instructed to think about how project-based learning impacted their understanding. As Figure 2 presents, more students said they had either a “very high,” “somewhat high,” or “medium high” level of understanding with project-based learning, and no students reported feeling like they possessed a “low” or “very low” level of understanding.

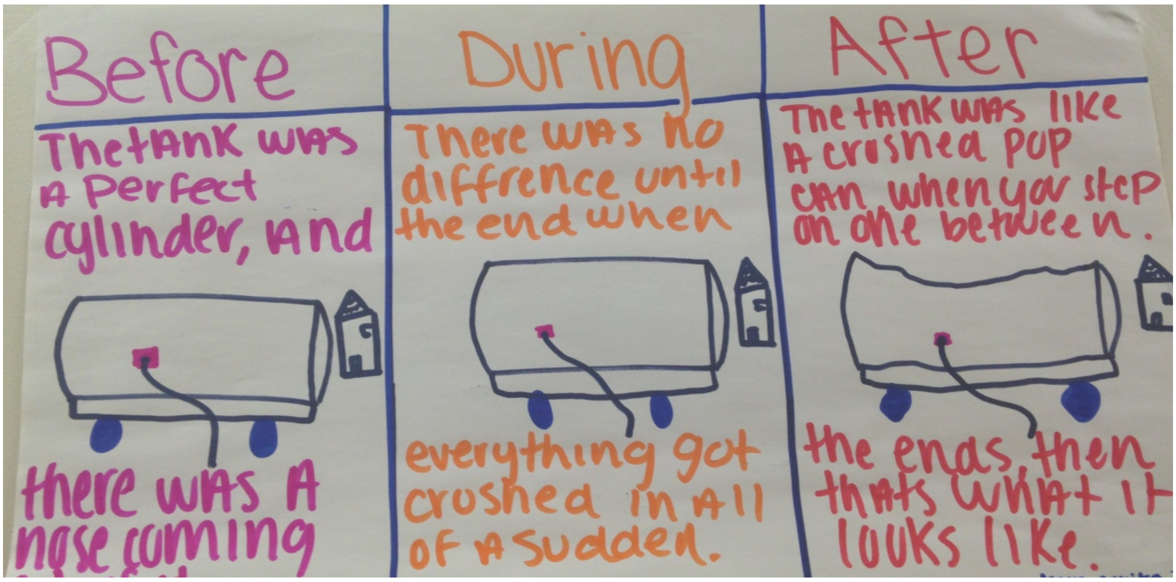
Figure 2. Student responses to “How well do you feel you’ve understood the chemistry content up to this point?”



This bar graph shows the percentage rate of each response category when the survey was taken before implementation of project-based learning and after implementation of the unit.

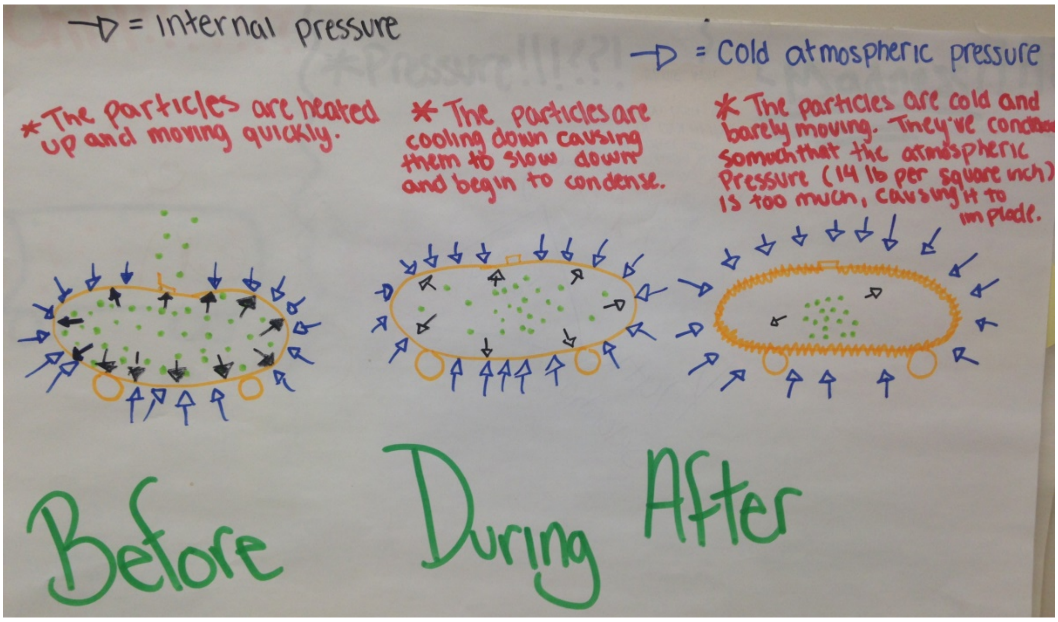
Student-generated models of phenomena were also considered as a third data set. Examples of student models at the start of the unit and end are included in Figures 3 and 4 below. Coding this data in a constant-comparative method highlighted several patterns between groups and across the unit.

Figure 3. One group's initial model of tanker phenomenon.



This model was created by a group of students at the very start of the unit before learning any of the learning objectives when they were instructed to explain what happened to tanker and why it collapsed.

Figure 4. One group's final revised model of tanker phenomenon.



This model was created by a group of students at the end of the project-based learning unit when they were instructed to explain what happened to tanker and why it collapsed.

Initial models described observations rather than offering explanations. Although students had been introduced to the idea of a scientific model, at the start of the unit these models were seen more as “poster presentations” that summarized observations of the phenomenon, as most groups simply represented “the what” rather than “the why” within their model. By the end of the unit, the models not only showed a summary of what was observed but also used a particulate model to explain why the tanker collapsed.

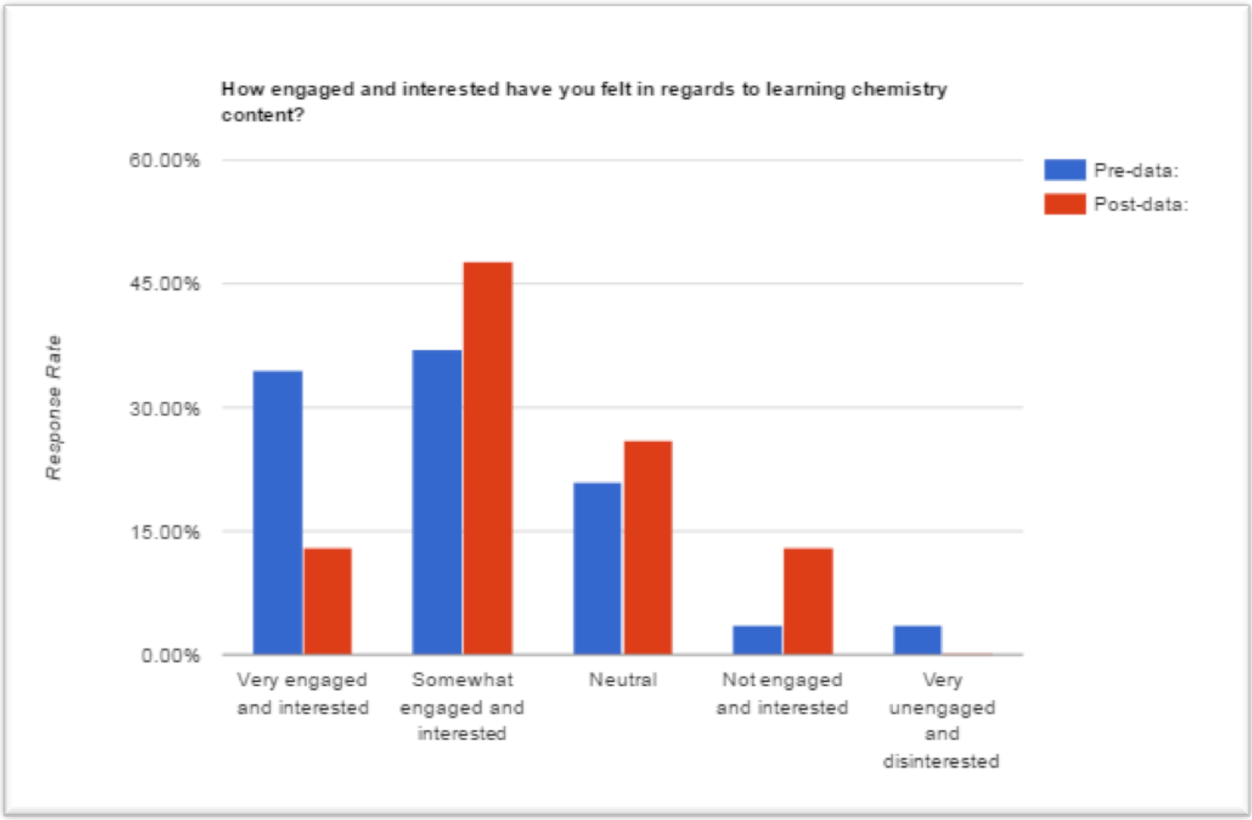
Initial models made knowledge gaps and misconceptions obvious. In many initial models, students either wrote or verbally used the word “suck” in their small group discussions to describe what was happening to the air in the tanker over time. Many assumed that such a dramatic change was an indication that a chemical reaction was taking place. Not one initial model included any mention of outside air pressure, instead focusing on what was happening inside of the tanker, but also failing to clearly represent that. Seeing these ideas represented in the works of so many students at the start of the unit allowed opportunities to directly and indirectly correct misconceptions.

Final models demonstrated understanding of the behavior of matter at a particulate level. Although students understood that matter was made of atoms prior to the start of this unit, groups did not add visual representations of these small particles of matter to their models until their final model. Final models showed that students realized matter, including invisible air, was made of small particles, and that these particles moved and behaved in predictable ways.

Relationships between temperature, pressure, and volume were clear in final models. Although some initial models failed to even mention these key unit vocabulary words, nearly all final models not only used them directly but demonstrated the direct and inverse relationships between these variables in the context of the tanker phenomenon.

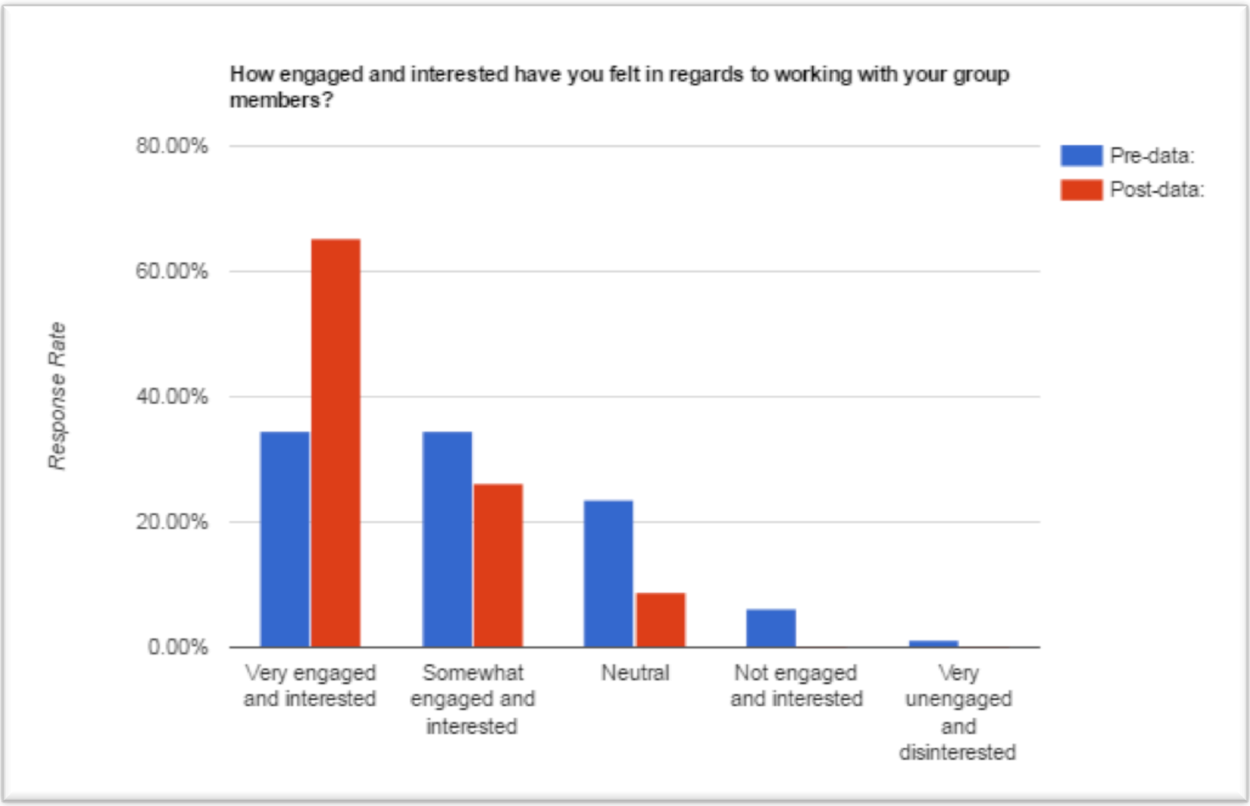
Action Research Question #2. To evaluate the second research question regarding student motivation and interest with science, students took a short reflective survey both before and after the unit. Questions asked them to self-assess their own interest in science, and results to the questions asked are summarized in Figures 5 and 6 below. Although no students reported feeling “very unengaged and disinterested in chemistry content” after implementation of this unit, fewer students indicated a high level of interest and engagement with content. However, a higher percentage of students reported feeling very engaged with their group members during this unit as compared to traditional unit.

Figure 5. Student responses to "How engaged and interested have you felt in regards to learning chemistry content?"



This bar graph shows percentage rate of each response category when the survey was taken before implementation of project-based learning and after implementation of the unit.

Figure 6. Student responses to "How engaged and interested have you felt in regards to working with your group members?"



This bar graph shows percentage rate of each response category when the survey was taken before implementation of project-based learning and after implementation of the unit.

This quantitative data was supplemented by informal teacher observations and reflections as well as opportunities for students to provide qualitative feedback in the form of exit slips. Most students were seen to be more engaged and interested as compared to prior units, and many made comments both informally and in their written exit slips to support this observation. One student even went as far as to claim, "This unit was overall the best unit we had all year" in an exit slip. In examining my own observations and students' written feedback, a few common themes emerged.

Teaching others helped develop understanding of content. My students loved working with the elementary students at the end of the unit, and many said that being asked to present as a summative assessment ensured that they better understood the chemistry content. For example, when asked to write me a letter about how the unit was going towards the end, one student shared, "I think Unit 6 went pretty good. The kids helped a lot to understand all the gas laws and I think our project was good because it helped the younger students understand the gas laws. It also helped us to explain it to them."

Students who had struggled before flourished. Social students who struggled to focus during note taking sessions blossomed when given opportunities to interact with group members on a daily basis as a primary teaching technique and were excited to come to class. Students whose low math skills had prevented their success in previous units valued the opportunity to create visual models and think about content conceptually rather than mathematically. I was surprised to see students who were quiet speak up and contribute to group discussions, raising their social status in the eyes of their peers as they phrased an observation or question in a particularly compelling way. It was inspiring to listen in on conversations and hear students I would normally expect to fail a written multiple choice test using accurate vocabulary to teach elementary students about the gas laws. As one student described, "I liked working with groups because we were able to put in all of our ideas and combine them. I liked doing a project for our grade because it was a different way to show our knowledge of the chapter."

Many students were confused initially. Not all feedback was positive. Several written comments mentioned the frustration experienced during this unit, especially at the start when the format felt so new. From a teacher's perspective, I saw students being challenged and could tell based on the number of questions I received each day that certain groups were struggling. However, as emphasized over and over, authentic science involves its fair share of frustration, but scientists who persevere through the confusion often have the greatest gains in understanding. Despite initial frustration, many students seemed to agree with this sentiment by the end of the unit, as represented in the following comment: "Unit 6 went well, at first I was confused about how pressure, temperature, and volume worked, but now I know how [. . .] At some points this unit was rough." Similarly, another student wrote, "The new teaching strategy was a little frustrating but by the end I think I understood it."

Traditionally successful students were frustrated. I encountered the most vocal frustration and resistance from students who had received the highest grades in previous chapters. These were students who knew "how to play the game" and had conquered traditional education and grading systems. When asked to collaborate with others rather than rely on themselves and to think critically rather than absorbing content knowledge to later regurgitate, these students asked many questions in search of "the right answer." One particular after-class conversation with two students stood out in my mind: "I don't understand why you won't tell us what the answer is," one said in reference to the tanker phenomenon early in the unit. That same student later wrote in an exit slip, “I hate PBL and hope we never do it again [. . .] I liked your old style of teaching better, sorry.”

The role of the teacher changed. Stemming from the frustration students experienced, I heard comments from students directly and even from colleagues who claimed that I had “stopped teaching.” Because I spent relatively little time standing at the front of the classroom lecturing as I had in prior units, students felt as if they were not being taught. One high-achieving student characterized this frustration in her exit slip feedback: “Unit 6 was okay. I did understand it, but the way we learned for this unit made it confusing. In my opinion, it was a little annoying having to do everything on our own. I would have comprehended this unit better if you would have taught it.”

Because I was not at the front of the classroom talking for most of the lessons, students perceived that I had “stopped teaching” them. What they did not realize was that they were thinking and learning for themselves in these moments, and that the teacher was still teaching, but in the role of learning facilitator rather than direct instructor.

Discussion

From these results, it can be seen that implementation of inquiry and project-based learning in the chemistry curriculum helped most students gain a better conceptual understanding of content as they were challenged to address prior misconceptions, represent their thinking in multiple ways, collaborate in order to construct an understanding of matter at the particulate level, and ultimately apply their learning by teaching others. In line with the literature review, this type of authentic learning can help address the flaws of the traditional education system represented in the works of Kolodner et al. (2003) and Krajcik and Blumenfeld (2006).

The increase in test scores as documented in this action research also aligns to the findings of similar studies by Mahendru and Mahindru (2001), Yadav, Lundeberg, Subedi, and Bunding (2011), and (Nguyen & Siegel, 2015). Just as Kazempour and Amirshokoohi (2013) reported that inclusion of inquiry-based learning led to a deeper conceptual understanding, my students’ data likewise served as evidence of their understanding of the learning objectives.

Although new techniques were implemented in this unit, it is important to note that group work and collaboration were skills that had been emphasized and practiced all year long.

The importance of communication and collaboration was not a new concept, and many structures and norms had been in place since the start of the school year to support successful student interactions, as recommended by Kolodner et al. (2003). In retrospect, I would argue that the time spent establishing and practicing these norms was critical to my students' success in this particular unit: rather than spending time learning how to work with others, students were able to focus on struggling with content together and thus were ultimately more successful.

Despite the fact that not all students preferred this style of teaching, many were seen to be more engaged and motivated to learn during class time, especially in populations of students for whom chemistry had been a challenge previously. Although minority students were not a particular focus of this research, seeing students who had struggled previously be so successful supports the conclusions of Buck, Cook, Quigley, and Prince (2014) regarding the positive impacts of an adapted science curriculum on the educational inequalities seen in minority students.

Undoubtedly, it would be unrealistic to presume that inquiry and project-based learning could (or should) be included in all units and lessons. However, expansion of this curriculum would no doubt help to alleviate the concerns and frustrations of students who were unused to such teaching methods. Implications for the future include the importance of establishing a culture of learning, collaboration, and critical thinking across the whole school year and within multiple classrooms to support all students' learning.

Despite its successes, limitations of this action research project are duly noted. Although effort was made to collect objective data, many of the observations were subjectively noted, resulting in conclusions grounded in qualitative data. The particular teaching context of my school also undoubtedly plays a significant role in the results of this study, and further research examining this type of learning in additional, more diverse classrooms may be warranted.

Conclusion

This action research project renewed my passion for teaching by challenging me to focus on maximizing student learning and engagement through authentic lessons grounded in real life. Although time consuming, I see the work put into the creation of these lessons as an investment in my teaching career, as I will continue to use and adapt them for years to come. Challenges and frustrations expressed by students were likely reflected in my own experiences, as this unit likewise pushed me to think critically and reflectively about chemistry content and best teaching practices. Although there were moments of doubt, overall the positive results that I saw in the majority of my students made all of the hard work and most of the frustration worth it in the end.

Because so many students engaged so deeply with this content, I hope to rearrange my curriculum next year in order to implement this unit in the fall semester. By enacting these lessons with students who have a rudimentary understanding of matter and little to no understanding of chemical reactions, I hope to build a particulate-level understanding of matter as foundation that will lead more students to be more successful in future units. Moreover, the skills applied in this unit will serve as practice for the units to follow; skills such as collaboration, questioning, and modeling can be utilized to construct understanding of more complex topics across the rest of the school year.

I also hope to adapt other units in a similar way, slowing building a repertoire of authentic, phenomena –based lessons that require students to develop their own understanding, represent their thinking in multiple ways, and communicate ideas for others. These are all science practices emphasized in the new Michigan Science Standards and utilized daily by scientists in the lab and field all over the world. By deepening my curriculum in this way, I hope to see less frustration from students as they become comfortable with being uncomfortable and as more structures are developed to support them as they grow as unique individuals, learners, and scientists.

About the Author

Michelle Vanhala is a science teacher at Tecumseh High School in Tecumseh, MI. Originally from Big Rapids, MI, she double majored in Integrated Science and English for Secondary Education at Central Michigan University, completing a capstone in transformative educational practices and receiving the 2014 Honors Program Senior Academic Honors Award. In 2014, she was named a Knowles Teaching Fellow through the Knowles Teacher Initiative, a national foundation focused on providing professional development and funding for the support of young math and science teachers. She recently completed a Masters of Science in Science Education through the University of Michigan - Dearborn with a focus on project-based and inquiry learning. Michelle is an avid reader and traveler and can be followed on Twitter through her handle @MsVanhala. Email: mvanhala@tps.k12.mi.us

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References

Albanese, M. A. & Mitchell, S. (1993). Problem-based learning: A review of literature on its outcomes and implementation issues. *Academic Medicine, 68*(1), 52 – 81.

Allen, D. E., Duch, B. J., & Groh, S. E. (1996). The power of problem-based learning in teaching introductory science courses. *New Directions for Teaching and Learning, 68*, 43-52.

Buck, G., Cook, K. L., Quigley, C. F., Prince, P., & Lucas, Y. (2014). Seeking to improve African Americans girls' attitudes toward science. *The Elementary School Journal, 112*(3), 431 – 453.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235 – 266.

Kazempour, M. & Amirshokoohi, A. (2013). Exploring elementary pre-service teachers' experiences and learning outcomes in a revised inquiry-based science lesson: An Action Research. *Journal of Education and Learning, 2*(2), 114 – 154.

Klahr, D., & Nigam, M. (2004). The equivalence of learning paths in early science instruction: Effects of direct instruction and discovery learning. *Physiological Science, 15*(10), 661 – 667.

Kolodner, J. L, Camp, P. J., Crismond, D., Fasse, B., Gray, J., & Holbrook, J. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by design into practice. *Journal of the Learning Sciences, 12(4),* 495-547.

Krajcik, J. S. & Blumenfeld, P. C. (2006). Chapter 19. *Project-based learning* (317 – 333). New York: Cambridge.

Nguyen, P. D. & Siegel, M. A. (2015). Community action projects: Applying biotechnology in the real world. *The American Biology Teacher, 77*(4), 241-247.

Mahendru, P. & Mahindru, D. V. (2011). Problem-based learning: Influence on students' learning in an electronics and communication engineering course. *Global Journal of Researchers in Engineering Electronics Engineering, 11* (8).

Schank, P. & Kozma, R. (2002). Learning chemistry through the use of a representation-based knowledge building environment. *Journal of Computers in Mathematics and Science Teaching, 21*(3), 253-279.

Schmidt, H. G. (1983). Problem-based learning: Rationale and description. *Medical Education, 17*, 11-16.

Yadav, A., Subedi, D., Lundeberg, M. A., & Bunting, C. (2011). Problem-based learning: Influence on students' learning in an electrical engineering course. *Journal of Engineering Education, 100*(2), 253-280.

Appendix A: Unit 6 Pre/Post Test

Unit 6 Pre/Post Assessment

Think back to the first few chemistry units and use your experiences to answer the following questions honestly.

1. How engaged and interested have you felt in regards to learning chemistry content? a. Very engaged and interested b. Somewhat engaged and interested c. Neutral d. Not engaged and interested e. Very unengaged and disinterested

2. How engaged and interested have you felt in regards to working with your group members?
a. Very engaged and interested b. Somewhat engaged and interested c. Neutral d. Not engaged and interested
e. Very unengaged and disinterested

3. Which of the following teaching practices makes you feel engaged and interested in chemistry? Bubble in all that apply! a. Ms. Vanhala going through examples b. Working in small groups c. Working with a partner d. Individual practice e. Hands on labs

4. How well do you feel you've understood the chemistry content up to this point? a. Very high level of understanding
b. Somewhat high level of understanding c. Medium high level of understanding d. Low level of understanding
e. Very low level of understanding

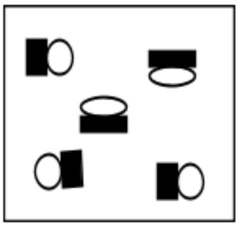
5. Which of the following teaching practices has helped you understand chemistry content up to this point? Bubble in all that apply! a. Ms. Vanhala going through examples b. Working in small groups c. Working with a partner d. Individual practice e. Hands on labs

Flip your bubble sheet over - on the back, list out any other teaching practices that help you feel engaged/interested and understand chemistry content!

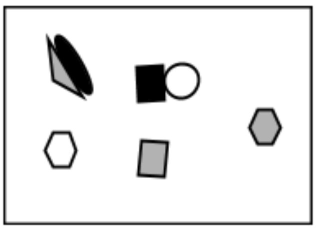
- [ ] **6.1 I can define element, compound, and mixture by identifying examples of each.**

6. Which of the following images below best represents a mixture of compounds and elements?
7. Which of the following images below best represents a pure compound?
8. Which of the following images below best represents a pure element?
9. Which of the following images below best represents a mixture of elements?
10. Which of the following images below best represents a mixture of compounds?

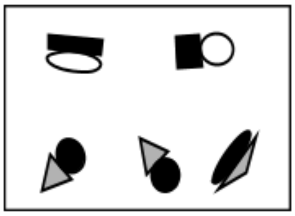
A.



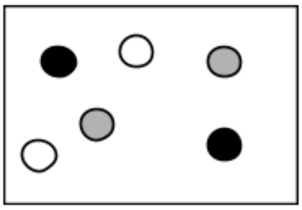
B.



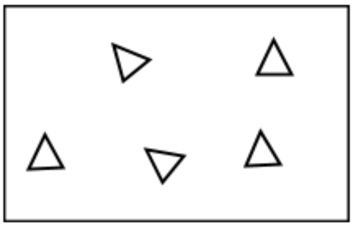
C.



D.



E.



❑ **6.2 I can compare inter- and intra-molecular forces by defining each.**

True (a) or False (b)?

11. (T/F) Intramolecular forces act internally to attach elements together in compounds while intermolecular forces work between neighboring particles externally

12. (T/F) Intermolecular forces act internally to attach elements together in compounds while intramolecular forces work between neighboring particles externally

13. (T/F) Both intermolecular forces and intramolecular forces attach elements together in compounds

14. (T/F) Both intramolecular forces and intermolecular forces work between neighboring particles externally

15. (T/F) Neither intramolecular forces nor intermolecular forces act internally to attach elements together in compounds or work between neighboring particles externally

❑ **6.3 I can describe polarity, dipole forces, hydrogen bonds, Van der Waals interactions, and electrostatic forces by identifying examples of each.**

16. Electrostatic forces	a. Attractive or repulsive forces between molecules caused by electrons in one affecting electrons in the other
17. Dipole forces	b. Attractive forces in which a hydrogen atom is weakly bonded to another negative atom
18. Hydrogen bonds	c. Attractive forces resulting from interactions between oppositely charged areas in polar molecules
19. Polarity	d. A molecule in which one side is slightly negative and the other side slightly positive
20. Van der Waals Interactions	e. Attractive or repulsive forces between molecules

❑ **6.4 I can distinguish between temperature and heat by comparing definitions and specific heat of substances.**

21. Temperature
    a. Is a measure of the average kinetic energy of a substance
    b. Has the same definition as the word “heat” in chemistry class
    c. Cannot go higher than 273 Kelvin
    d. Is not related to the movement of particles in a substance
    e. All of the above

22. Which of the following would have the most similar **average kinetic energy** of its particles?
    I. liquid water at 80.0 ºC
    II. solid steel at 0.0 ºC
    III. solid steel at 80 ºC
    IV. liquid methanol at 60.0 ºC

    a. I and II   b. I and III   c. II and III   d. I and IV

23. The particles of the 10.0 kilogram mass of iron at 290 degrees Kelvin will have the same **average kinetic energy** as the particles of a 10.0 kilogram mass of paper at 290 degrees Kelvin.
   a. True
   b. False

24. Specific heat is
a. The same as "temperature"
b. A amount of energy required to raise a substance's temperature
c. Cannot go higher than 273 Kelvin
d. Is a measure of the average kinetic energy of a substance
e. All of the above

25. True (a) or false (b)? Water has a relatively high specific heat.

❑ **6.5 I can explain what happens to the kinetic energy of a substance as temperature is increased using the kinetic theory of matter.**

26. Which of the following is NOT true about the kinetic theory of matter?
   a. The kinetic theory of matter states that in all forms of matter the particles are in constant motion.
   b. The kinetic theory of gases assumes that the particles of a gas are small, solid particles.
   c. The kinetic theory of gases assumes no energy is lost when the particles collide.
   d. The kinetic theory of gases assumes that gas particles have random motion.
   e. The kinetic theory of gases assumes that gas particles have a lot of intermolecular forces of attraction.

True (a) or false (b)?

27. (T/F) Kinetic energy and temperature have an inverse relationship.

28. (T/F) As temperature increases, so does the average kinetic energy of a substance.

29. (T/F) A change in temperature occurs during a phase change.

30. (T/F) The energy added to a boiling liquid is lost as water is vaporized, keeping the average kinetic energy of a boiling liquid (at constant pressure) the same.

❑ **6.6 I can distinguish between the four states of matter by describing their kinetic energy and strengths of internal attractions.**

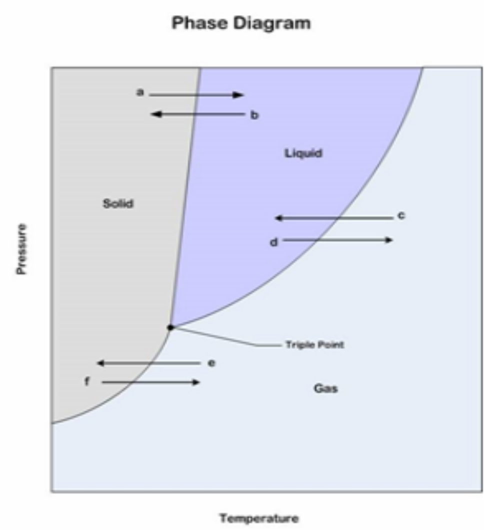
31. Solid
32. Liquid
33. Gas

a. b. c.

34. Which of the following states of matter has the highest kinetic energy?
a. solid b. liquid c. gas d. plasma e. all have the same

35. Which of the following states of matter has the highest intermolecular forces?
a. solid b. liquid c. gas d. plasma e. all have the same

❑ **6.7 I describe phase changes using correct vocabulary and particle diagrams.**



36. In the phase diagram, what best describes what is happening at the triple point?
a. Only the solid state can be found
b. Only the liquid state can be found
c. Two states of matter can be found at the same time
d. All three states of matter can be found at the same time
e. None of the states of matter can be found at this point

37. In the phase diagram, what best describes what is happening at point F?
a. The solid is sublimating into a gas
b. The solid is melting into a gas
c. The gas is sublimating into a solid
d. The gas is condensing into a solid
e. The critical point is occurring

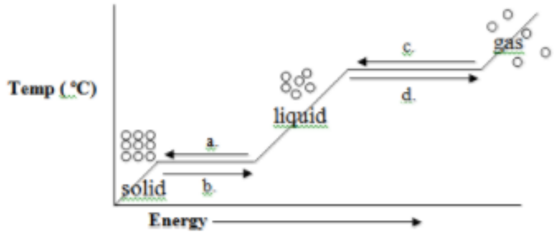
38. In the phase diagram, what best describes what is happening at point D?
a. The liquid is vaporizing into a gas
b. The gas is vaporizing into a liquid
c. The gas is condensing into a liquid
d. The liquid is condensing into a gas
e. The solid is melting into a liquid

39. In the phase diagram, what best describes what is happening at point A?
a. The liquid is melting into a solid
b. The liquid is freezing into a solid
c. The solid is melting into a liquid
d. The solid is freezing into a liquid
e. The liquid is vaporizing into a gas

40. Which of the following is most accurate regarding the phase diagram above?
a. Gases exist at a relatively low temperature and low pressure
b. Solids exist at a relatively low temperature and high pressure
c. Liquids exit at a relatively high temperature and low pressure
d. The triple point occurs at a relatively high temperature and high pressure
e. All of the above are true

❑ **6.8 I can create a phase change diagram to model the energy of a substance as temperature changes over time.**

41. Which of the following is true about the phase change diagram?
    a. At location A the substance is solid only
    b. At location B the substance is both solid and liquid
    c. A location C the substance is a liquid only
    d. A location D the substance is both liquid and solid
    e. All of the above are true



42. Which of the following is NOT true about the phase change diagram?
    a. The temperature is staying the same at A and C
    b. The temperature is increasing at B and D
    c. Heat energy is being removed at A and C
    d. Heat energy is being applied at B and D
    e. A solid is being heated until it is a gas

43. During freezing
    a. temperature increases
    b. temperature decreases
    c. temperature stays the same
    d. temperature varies indirectly

44. During freezing
    a. energy increases
    b. energy decreases
    c. energy stays the same
    d. energy varies indirectly

45. Which of the following is true of water freezing?
    I. the average kinetic energy of the particles remains constant
    II. the average kinetic energy of the particles decreases
    III. the total kinetic energy increases
    IV. the total kinetic energy decreases

    a. I and III b. I and IV c. II and III d. II and IV

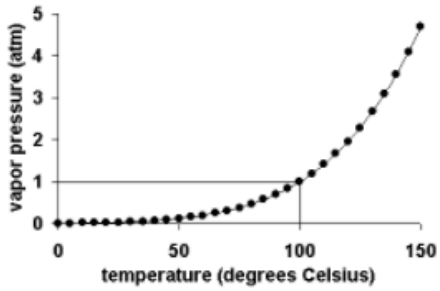
❑ **6.9 I can characterize the relationships between pressure, temperature, and volume by using Dalton's Law, Boyle's Law, Charles' Law, Gay-Lussac's Law.**

46. Which of the following indicates the relationship between volume and pressure for a mass of a gas at a constant temperature?
    a. volume increases as pressure increases
    b. volume decreases as pressure increases

47. Which of the following indicates the relationship between pressure and temperature for a mass of a gas at a constant volume?
    a. pressure increases as temperature increases
    b. pressure decreases as temperature increases

48. Which of the following indicates the relationship between volume and temperature for a mass of a gas at a constant pressure?
    a. volume increases as temperature increases
    b. volume decreases as temperature increases

49. The following graphs shows the relationship between the temperature and pressure of a fixed mass of gas. The relationship between these two variables is



    a. direct (as one increases the other also increases and vice versa)
    b. inverse (as one increases the other decreases)

50. As the temperature drops, what will happen to the air pressure in your car's tires?
    a. Pressure will increase
    b. Pressure will decrease
    c. Pressure will stay the same
    d. Pressure will increase and then decrease

❑ **6.10 I can calculate pressure, temperature, volume, and moles using the Combined and Ideal Gas Laws.**
R = .08206 L atm mol^{-1} K^{-1}

51. A gas is contained in a 2.0 L rigid vessel (so volume is constant) and the has a temperature of 50.0 K and a pressure of 0.0010 atm. What will the pressure be at a temperature of 200.0 K?
    a. 0.0020 atm b. 0.0040 atm c. 0.00050 atm d. 0.00025 atm

52. A gas is kept at a constant temperature of 0.0 ºC and has a pressure of 700.0 mm Hg and a volume of 55.0 mL. What will its volume be at 965 mm Hg?
    a. 3.63 mL b. 75.8 mL c. 39.9 mL d. 1.22 x 10^4 mL

53. A 2.0 L rigid container contains 0.40 moles of a gas at 20.0 ºC. What is its pressure (in atm)?
    a. 4.8 atm b. 2.4 atm
    c. 0.60 atm d. 0.30 atm

54. How many moles are there in a gas which has a volume of 3.50 L, a temperature of 20.0 ºC, and a pressure of 1.00 atm?
    a. 1620 mol b. 111 mol c. 0.145 mol d. 6.87 mol

55. What is the pressure of 1.2 moles of a gas which has a volume of 1.520 L and a temperature of 40.0 ºC?
    a. 0.0493 atm b. 20.3 atm c. 0.0203 atm d. 1.59 atm