

Why is the Good Stuff at the Bottom of the Cooler? An Inquiry about Inquiry for Preservice Secondary Science Teachers

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Abstract

The following article describes a lesson that was originally implemented in a high school chemistry classroom for the purpose of teaching students about density and was subsequently revised in order to teach preservice science teachers about inquiry and the practices of science. Lesson plans turned in after the experience revealed that preservice teachers demonstrated an understanding of the importance of allowing students to engage in the practices of science in order to construct their own meanings of natural phenomenon prior to being provided with an expected result. Practical examples of how science investigations can be modified for the purposes of science teacher preparation are included.

Introduction

As a high school chemistry teacher, I found myself frustrated when I had trouble figuring out ways for my students to develop their own research investigations. I could take a cookbook style laboratory and modify it so that students were generating their own procedures, but I struggled with providing opportunities for my students to pose their own investigative questions and to construct their own explanations for their findings. As a result, I felt that I was an “inquiry failure”. As a preservice teacher (PST), I had learned about open-ended inquiry in science methods courses and thought of it as a gold standard and that anything less fell short of a decent inquiry experience for my students. That is, until I was introduced to a particularly informative article in *The Science Teacher* that transformed my view (Bell, Smetana, & Binns, 2005). In this article, Bell and colleagues offer the following demarcation criterion for identifying whether or not a classroom activity qualifies as inquiry-based in the first place. Inquiry-based activities must involve students answering questions through a process of data analysis. From there, inquiry-based activities are classified based on who is posing the question, who is proposing the methods for data collection and analysis, and who is constructing the conclusions. This simple definition paired with the continuum of ownership described above helped me to realize that my high school chemistry classroom was really much more inquiry-based than I had given it credit for.

I have subsequently used one of these classroom inquiries, involving the comparative analysis of the densities of diet and regular soda, that was a regular feature in my chemistry classroom, in my preservice secondary science methods courses to introduce my PSTs to the features of inquiry and more recently to the relationships between the practices of

science as discussed in the Next Generation Science Standards (NGSS) (NRC, 2012) and those features. It was also my hope that my PSTs would be able to learn from my experiences as a high school science teacher and subsequently be able to demarcate between inquiry and non-inquiry in the secondary science classroom. They would also be able to experience first-hand what it is like to participate in a scientific investigation prior to witnessing a related demonstration and to discuss the impacts of the sequencing of a science activity. Additionally, the topic of density relates nicely to the disciplinary core idea PS1-A: Structure and Properties of Matter and the crosscutting concepts of scale, proportion, and quantity in the NGSS (NRC, 2012). This lesson could easily be extended to include discussions with the PSTs about the features of the NGSS.

In the sections below, I will describe the activity as it was most recently implemented in my methods course and then offer some possible suggestions for improvement. Additionally, I will discuss what I believe were the benefits for my PSTs that accompanied their participation in this activity. Finally, I will offer some advice for other science teacher educators who work with preservice and inservice teachers as they encourage them to plan engaging science lessons that align with the NGSS.

Overview of the Activity

The experience outlined in this article is not unlike a classic undergraduate chemistry laboratory described elsewhere (Herrick, Nestor, & Benedetto, 1999). The basic summary of the lesson is that students engage in an investigation to compare the densities of diet and regular soda. In addition to high school chemistry classes, I have facilitated the activity in both elementary science methods courses and secondary science methods courses that I have taught at multiple universities over the past few years. What will be shared is the most recent iteration as implemented in a secondary science methods course. The innovation in this particular activity is not found necessarily in the activity itself. Measuring the density of soda is a rather common experience in a science classroom. Rather, the novel nature of the ideas presented in this manuscript comes through the sequencing of the lesson in order for the preservice science teacher to explicitly experience an exploration of a phenomenon before it is explained. In a parallel manner, the PST engages in an inquiry-based activity prior to learning about the inquiry continuum. Thus PSTs are inquiring about inquiry. For many, this may be a novel approach to preservice science teacher instruction where PSTs may participate in plenty of hands-on and inquiry-based approaches without taking the time to deeply reflect on the implications for future classroom practice.

The Activity as Implemented in my High School Classroom

The original idea for this activity came from seeing and subsequently performing the classic demonstration in which an unopened can of soda is placed in a large beaker of water after students make a prediction about whether it will sink or float. My high school chemistry students would observe the can of diet soda floating and the can of regular soda sinking. I

would follow-up with a discussion about how at family reunions growing up I used to be disappointed when opening up the drink cooler and to my dismay seeing only diet soda. In reality the good stuff was just at the bottom of the cooler and I should have been brave enough to plunge my arm through the ice and cold water to fish for something that was not artificially sweetened.

This activity was then followed up with a laboratory investigation where my students would calculate and compare the density of regular and diet soda by implementing a procedure of their own development utilizing a 100mL graduated cylinder and a triple beam balance. The students seemed to enjoy the lab and it was something I made sure to include every year in my chemistry curriculum.

The Activity as it has Evolved for the Purposes of Preservice Secondary Science Teacher Education

When I transitioned to teaching in higher education and began working with a PST population, this same activity seemed like it would be a great example of scientific inquiry to model with my university students. However, the purposes of the activity were no longer merely to learn about density, but rather to experience an inquiry to learn about how inquiry-based activities can be conducted in a secondary science classroom. This objective has since evolved to now include discussions related to how inquiry as previously defined (NRC, 2000) aligns with current views of the practices of science found in the NGSS (NRC, 2012). Specifically students engage in planning and carrying out of investigations, analyzing and interpreting data, using mathematics and computational thinking, and constructing explanations.

Additionally, I realized that by using the demonstration (sink or float) at the beginning of the laboratory activity, I was in essence making the experience an example of a lab conducted at the level of a confirmatory inquiry. The students would know which type of soda should be less dense than the other after seeing which can floated. So the first and most obvious change I made was to move the demonstration to the end of the activity. What follows is a step-by-step presentation of the revised version for preservice secondary science teachers.

The experience begins with the instructor distributing a number of unopened cans of diet and regular soda to the PSTs. It doesn't matter which brand except to have the brands match and to select something that you like so as to enjoy the leftovers. The PSTs are then asked to brainstorm the properties of the soda that could be investigated scientifically. PSTs then share their thoughts. Typical responses of things that could be investigated include sugar content, amount of calories, caffeine content, amount of dissolved carbon dioxide, density, etc.

In all likelihood, the PSTs will on their own identify density as a property of the soda that they could investigate. Had the floating and sinking demonstration been at the beginning of the activity, the PSTs almost certainly would have had a rationale for choosing density to study. Because I made the previously discussed decision to move the demonstration to the end of the activity, I have found that on occasion I need to explicitly encourage the PSTs to investigate density. One rationale that I use to do this is that the equipment we have in the teaching laboratory is conducive to the measurement of this property. If we had a mass spectrometer in the college of education, that would not necessarily be the case, as we could measure many more things than simply density.

The PSTs then as groups (typically 3-4 students) develop a research question and methods utilizing the equipment at hand (a 100mL graduated cylinder and a triple beam balance). The research question usually has resembled something like, “How does the density of diet soda compare to the density of regular soda?” PST procedures typically involve multiple trials in which different volumes of soda are poured from an open can into the graduated cylinder. For each trial, PSTs allow the fizz to settle and then record the volume. The graduated cylinder containing soda is then placed on the triple beam balance and massed. Once their methods have been approved, PST groups begin their investigations. Inevitably one or more groups will forget to subtract the mass of the empty graduated cylinder and subsequently calculate grossly inaccurate densities.

I then have the PSTs come up to the front of the classroom and enter their data into a previously created Excel spreadsheet complete with formulas that automatically calculate the densities and average the pooled data. Using Excel, it is simple for the PSTs to create a graph for both the diet soda and the regular soda by using each paired mass and volume as a data point. A line of best fit can then be displayed in which the slope of the line is equal to the density. Pre-service teachers then discuss why it is that the slope is equal to the density and what the consequences would be if the measurements were plotted on the opposite axes. Two sample graphs containing simulated but realistic data are presented below as figures 1 and 2.

Figure 1 (Click on image to enlarge). Density of diet soda graph.

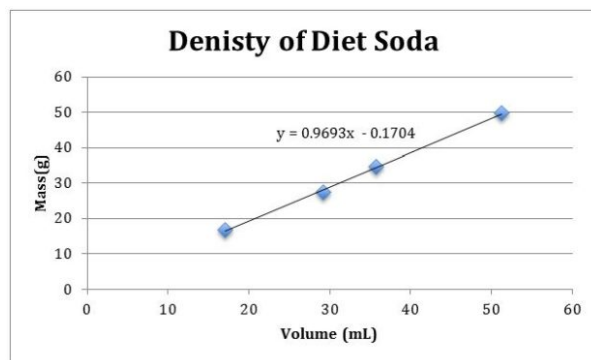
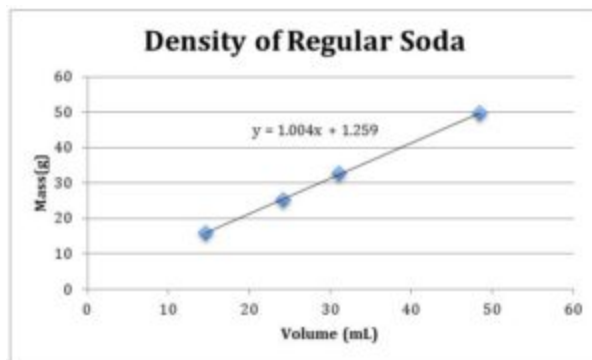


Figure 2 (Click on image to enlarge). Density of regular soda graph.



The PSTs are then able to posit, providing evidence, that the regular soda is indeed denser than the diet soda. Specifically, the average density of the regular soda should be slightly greater than 1.00 g/mL and the density of the diet soda should be slightly less than 1.00 g/mL. I then ask the PSTs to read the labels of the respective cans of soda and see if they can develop an explanation for why one is denser than the other. The first thing they will notice is that the only notable difference is that regular soda contains high fructose corn syrup and diet soda contains aspartame. Both of these ingredients are used to sweeten the beverages. I then provide PSTs with the formulas for both compounds and allow them to calculate the molar mass of each. Glucose has the following formula: $C_6H_{12}O_6$ and has a molar mass of 180.16 g/mol. Aspartame has the following formula: $C_{14}H_{18}N_2O_5$ and has a molar mass of 294.3 g/mol. Figures 3 and 4 display the structural formulas of these respective molecules.

Figure 3 (Click on image to enlarge). Fructose.

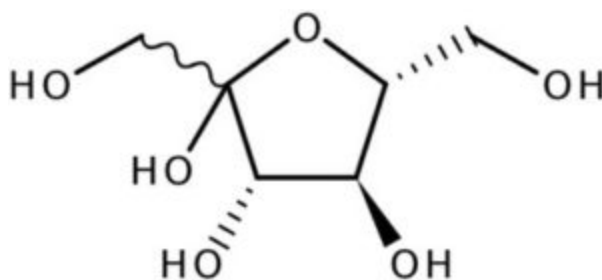
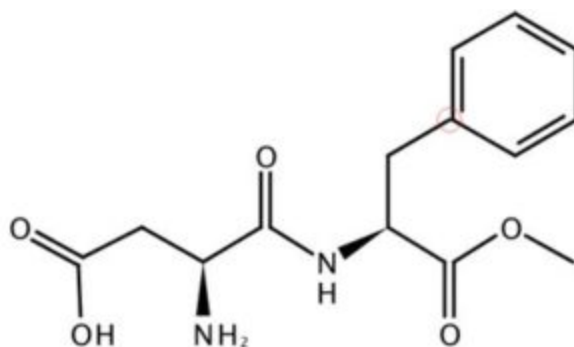


Figure 4 (Click on image to enlarge). Aspartame.



Even from glancing at the images of the structural formulas, PSTs will correctly realize that aspartame is a much larger molecule than is fructose. This evidence seems contrary to the results of the investigation. Since diet soda is sweetened with aspartame, PSTs will wonder why it was not denser than regular soda, a common misconception. The reason has to do with the order of ingredients as listed on the can that, as most PSTs will be able to identify in discussion, are listed in order of abundance. Fructose is the second most abundant ingredient in regular soda behind carbonated water and aspartame is the third or fourth most abundant ingredient in diet soda depending on the brand of soda used. Aspartame therefore is a more powerful sweetener. In other words, it takes less of it to get the job done when compared to fructose. Following this discussion, PSTs then witness the “will it float” demonstration that was previously described after making predictions based on the evidence obtained from the density investigation.

It is at this point that I transition to a discussion of the components of inquiry that PSTs just experienced. I start by pointing out the five essential features of inquiry (NRC, 2000). I then move on to a discussion of Bell et al.’s (2005) clearly identified levels of inquiry and a discussion of the continuum from confirmatory to open-ended inquiry. Specifically I have the PSTs tell me what level of inquiry they thought the density activity was exemplifying. Most can clearly identify that it was not confirmation (because I moved the demonstration to the end) and not structured (because I had them develop procedures). I want PSTs to be able to identify the levels of inquiry so that they can do so with their own future lessons. I do this with the hopes of encouraging PSTs that they likely are engaging their students in inquiry even if it is not open-ended. I also have the PSTs brainstorm what the impact would have been if they had witnessed the demonstration prior to the investigation. The discussion closes with an examination of the NGSS (NRC, 2012) and the practices of science. They clearly see that they were involved in asking questions, planning and carrying out investigations, analyzing and interpreting data, using computational thinking, and constructing explanations. We then finish the lesson with a discussion of how the practices of science just listed are a larger umbrella under which the essential features of inquiry fall. PSTs are then instructed to clearly identify both a research question and the analysis of data within an upcoming inquiry-based lesson plan that they will individually write. This lesson plan will need to allow students to engage in the practices of science before they are provided with or generate an explanation. PSTs also need to create objectives for this lesson that are tied to the NGSS and specifically involve the practices of science.

Impact of the Activity and Discussion

Based on lesson plans that PSTs created, and observations of them teaching in secondary science classrooms during concurrent field placements, I am confident that the activity just described was effective. Not only did the students enjoy the activity, they were also able to put into practice their new knowledge about inquiry. Specifically, PST lessons designed to engage students in inquiry created after the experience clearly had their students analyzing

data in order to answer research questions. Additionally, these PSTs were able to write lessons that had students engage in explorative investigation prior to the explanation of the phenomenon in question. In fact, one of my PSTs even chose to investigate the impact of the order of exploration/inquiry investigations within the sequence of a lesson on student achievement in his required action research project.

The above example lesson has been presented as a model for other science teacher educators to follow as they attempt to take an activity that they have performed in their own K-12 teaching experiences and modify in ways that would allow for them to teach others how to teach similarly effective lessons. I would encourage science teacher educators (many of whom started their professional careers as science teachers) to reflect on an inquiry-based activity that their PSTs used to enjoy. They could then take this activity, and have their PSTs perform it in class with the focus of using it as a model for lesson planning and reflective discussion.

I recall in my own teacher preparation program participating in many activities that I could potentially one day engage my own students in only after instruction on research-based conceptualizations of how to effectively teach science. I was being told to have my students construct their own understandings of natural phenomenon prior to me offering an explanation. However, I was only experiencing an inquiry-based activity after an explanation of what inquiry was within my own preparation to become a teacher. Looking back, this seems a bit hypocritical. I structured the above activity to combat this seeming contradiction. It illustrates how engaging future science teachers in an inquiry/scientific investigation can allow for them to analyze the experience and think about and reflect upon how it relates to both current issues in science education and to their future classroom practice. The activity also is a nice example of the importance of exploring before explaining both in terms of why the location of the demonstration in the sequence of the lesson mattered and why it was useful to explain the science education content (i.e., the practices of science, the essential features of inquiry, the levels of inquiry) after the PSTs had participated in an inquiry themselves. Finally, I personally like how the experience allows for PSTs to see that the practices of science as outlined in the NGSS (NRC, 2012) really are accomplishing the same purposes that inquiry once did within science education.

Suggestions for Possible Modification of the Activity

One critique that could be made about this lesson is that, due to the placement of the demonstration at the end of the experience, there is definitely the potential for the instructor to need to steer the PSTs towards a specific research question. For this reason, it may be hard for the PSTs to clearly label the level of inquiry for the activity they just completed. One modification then would be to open the lesson with the demonstration being used as an impetus to develop an investigation to explain the phenomenon the PSTs just witnessed, and then return to the demonstration again at the end to test their theory of the relationship between density and buoyancy. Specifically, after the lesson, the demonstration could be

performed using a beaker of salt water instead of tap water. This would increase the density of the solution in the beaker and would result in both cans floating as now they would both be less dense than the salt water. Now PSTs would be required to use claim, evidence, and reasoning in a different context.

Acknowledgement

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