Instructional Context

This introductory chemistry class meets each day during second block and is my largest class- 27 students total. Eleven students are sophomores- ages 15-16. Eleven students are juniors- ages 16-17. The remaining 5 students are seniors- ages 17-18. This set of 27 students is composed of 20 white students, 5 black students, and 2 Hispanic students. The class is absent of English Language Learners.

Even with the large range of ages and ethnicity, the true diversity of this classroom arises in the ability level of each student. Overall, the classroom can be divided into two groups- the students with a genuine interest in science and the students interested in earning their 4$^{th}$ science credit requirement. Because as an accomplished science teacher I know my students as individuals, I sought to find activities that would generate an interest in science for those enrolled for the credit, would be relevant for this science course, and also would create curiosity for those already knowledgeable.

Because this classroom illustrates great diversity in many areas, students with exceptional ability and needs are present at both ends of the spectrum. This classroom has 4 TST (Teacher Support Team) students and 9 gifted students. My TST students have poor literacy skills and a lack of motivation. At least 2 of my gifted students struggle in my class but excel in their English and history classes. Therefore, as a skillful science teacher who employs deliberately sequenced, research-driven instructional strategies, I searched for activities that would challenge students regardless of their ability and that would also encourage collaboration between students with different abilities. As a result, my students performed an experiment at home, engaged in active inquiry via an online simulation, and with the aid of graphic organizers (GO) composed an analysis essay.

Planning Instruction

As an accomplished science teacher, I create multiple opportunities for students to examine science and its history as well as its connection to technology so my students can easily connect science and its effect on their lives. Consequently, this entry focuses on students as they develop a deepening understanding of the *8 major aspects* of the Nature of Science (NOS). Over a span of 9 weeks: 1.) Students studied and participated in their own *experimental design process*. 2.) They also entered into multiple discussions comparing *observations* made to *inferences* drawn based on those observations. 3.) During a molecular shape discussion, they differentiated between *science's laws* and its *theories*. 4.) Through atomic history discussions, they witnessed *science's tendency to change* as well as how differing opinions in science make it *partially subjective*. 5.) Finally, through personal experiments and research, they identified science's foundation in *society and culture*.

My overarching goal was to develop such a deep understanding of NOS that students could easily identify how these 8 aspects affect not only chemistry but also daily life. Also, I hoped to continually challenge my top students who had greater prior knowledge while providing a relevance to the science course for those taking the class just for graduation. I designed my unit to easily highlight and clarify the common misconceptions students hold concerning science's observations and inferences, science's subjectivity, and its effect on society and culture.

Engaging my students in in-depth discussions and analysis of NOS is one of my most important teaching units. Students approach chemistry from a multitude of viewpoints. I find they have been exposed to NOS in bits and pieces, but they do not grasp its relevance to science; this puts them at a disadvantage, especially when learning chemistry concepts. For example, the discussion that evolved concerning climate change when we were learning about energy unit conversions had the students more engaged when, using even rudimentary NOS skills, they were able to relate a chemical concept to a real-world problem. They took ownership of the benchmark content in a way that was not evident last year, proving the value of NOS activities.

The discussion and application of the NOS wove itself through 4 chemistry units- unit conversions, atomic history, atomic theory, and chemical bonding. In week 1, I introduced the concept of NOS by assessing my students' prior knowledge of the scientific method and experimental design. They read an article chronicling a geologist's quest to discover what had killed so many evergreen trees. Afterwards, they identified steps of the scientific method they saw represented in the article. After my students had developed a basic understanding of the scientific method, I next obtained a more precise idea of their prior knowledge of NOS by using a worksheet with statements about science asking them to agree or disagree with each. The class discussion of these statements led to our formal lecture that defined the 8 aspects of NOS.

In order to connect NOS to chemistry content (unit conversions) as well as to their personal interests, the students found a current environmental event article that interested them and then used the Idea-Details strategy to summarize the article. As a result, the class discussion of the articles was personal and relevant to their interests. This dialogue led to climate change and the data scientists use to track climate change, learning to convert between energy units like the Joule, the erg, etc. The exercise even taught them to convert the kWh consumed in homes into the amount of $CO_2$ that was released into the air (in kg $CO_2$).

At the end of week 1, my students tested on unit conversions and NOS and embarked on a 4 week home experiment. They were asked to read their power meters each day, recording the home kWh consumption for a week. Then students tried to determine which items in their home consumed the most power and considered practical ways their families could conserve energy.

For the next 3 weeks, each student tried to conserve energy and reduce the amount of $CO_2$ released. Each week, they converted their weekly kWh consumption into $CO_2$ output and also described in a journal the success of their experiment. At the end of the 4th week, students wrote 2 journals- each describing how they witnessed one aspect of NOS during the experiment (Activity #1). Wanting to improve students' weak writing skills, each student was asked to brainstorm by filling out a GO we had reviewed in class. The journals revealed each student's base-line understanding of NOS to compare their future work against for evidence of growth and to help me plan the next step in building their knowledge of NOS.

During the 3rd week, while they were conducting home experiments, we discussed the history of the atom in class and moved our knowledge of NOS beyond basic understanding to my overall goal—application. Because the application process is more difficult, I used the history of science to illustrate how scientists apply NOS in various situations. I created a time-line that each student could color-code beginning with the discussion of matter and ending with the Modern Atomic Theory. Each section was color-coded based on the exemplified aspect of NOS. For instance, Aristotle's and Democritus's disagreement on matter's composition was color-coded to represent that science is "partially subjective." In this manner, I reinforced the concepts of NOS while modeling the application of NOS through "great moments" in chemistry.

During week 5, students showed their deepening understanding by applying 4 aspects of NOS to an inquiry activity concerning the varying models of the hydrogen atom (Activity #2). My students engaged in the assignment using PhET technology- an online simulation- and explained how we derived the modern model of the atom using NOS. The students completed the process by using an inquiry-supported hand-out. This assignment expanded their depth of knowledge of

NOS beyond reflection and into discussion, while also mastering chemistry content. Class work during weeks 6 and 7 reinforced NOS specific to chemistry content.

In week 8, we explored the contrast of scientific laws versus scientific theories as we discussed covalent bonding and molecular geometry. As a result, by week 9, I had covered all 8 aspects of NOS and provided examples of each in our chemistry discussions. Consequently, I assigned a culminating assessment, broken into 2 parts. In part I, I had them read statements, identify which aspect of NOS was represented, and then justify their conclusion, showing any lingering misconceptions held by each student. Based on this assessment, I then assigned one of these misconceptions to each student. Using our classroom IPads and their GO app, the students found a current event article that explained their NOS concept and wrote an analytical essay justifying the article as an example of their aspect. This activity showed if my students could transfer their NOS knowledge acquired through chemistry-based units to a wide-variety of applications, demonstrating true mastery.

Two misconceptions became challenges as I planned this instructional sequence- a poor understanding of experimental design and poor or misinformed concepts of observations and inferences. As a result, I designed specific activities that would require students to work through these misconceptions instead of merely memorizing the new answer. For instance, my students left previous ideas about science's cyclical nature behind as they designed and performed their energy experiments. They also refined and improved their instinctual understandings of the nature of observation and inference by investigating each concept through inquiry and the PhET simulation in Activity 2.

One challenge did arise in the middle of the nine week sequence, causing me to adjust my initial plans. I had an abnormal amount of students this semester that chose not to do homework or projects. As a result, when my students wrote their final essay on NOS, I used two days of class time to investigate and write. This allowed me to truly analyze and review their growth of knowledge instead of my students just not completing the work.

When planning a unit, I base content and standards on state curriculum and the NSS. All assessments also check for one of two criteria- developing knowledge or developing problem solving skills. Throughout the activities, I consistently performed informal knowledge assessments through Socratic questioning, activity monitoring, etc. In this unit, I used four unit tests as formal assessments to calculate growing understanding. My students learned test format and weight the first day of school. I also used rubrics to assess the experiment, journals, and essays as another alternate means of assessment. The students were presented with these rubrics.

Analysis of Instruction and Student Work

The three assignments chosen for this entry build upon one another in substance and critical thinking through reflection, application, and analysis. Assignment 1 asked students to reflect on their energy experiment and how the different aspects of the NOS presented themselves. The journals revealed their developing knowledge of NOS and guided my design of later assignments. The second assignment asked students to extend their knowledge beyond simple classroom experiments and into classic atomic theory experiments. Lauren, student A, demonstrates her growing understanding when she moves from reflecting on how "observation is *something* noted about *something* in the world" in Assignment 1 to discussing how "scientists gain knowledge by using observations. . . *notic[ing] the 'energized electrons'*. . . making different models of the atom" in Assignment 2.

The final assignment pushed my students by requiring analysis of a current event article and its connection to an aspect of NOS that they once struggled with. They relied on their already developed skills of experimental design and application of NOS to find an article concerning their topic. By having them wrestle with a misconception and then explain how that aspect is demonstrated, my students moved from reflection and application into analysis.

As an accomplished teacher, one of my priorities in lesson planning is the design of relevant activities that students connect to daily life. For instance, I personally knew Lauren, Student A, for three years before teaching her this semester. Over those 3 years, I discovered that Lauren is a naturally curious and artistic girl who strives to please- her parents, teachers, and friends. She also expects herself to do well especially in science because as a kinesthetic learner she naturally enjoys her science classes. Consequently, knowing that I was also teaching friends of Lauren who competed with her for the top grades in classes, I designed Activity 1 to bring NOS directly into their homes and to provide the opportunity to actively participate in a scientific experiment concerning today's hot topic in science- climate change. In the same manner, Activity 2 challenged these naturally curious students to apply their developing NOS skills via inquiry.

However, my lessons are not only created to engage the interests of the top 10% in my classes, but also establish connections for students like Zach, a junior taking chemistry for the science credit. He is a quiet student who tends to miss class often which drastically hinders his learning because he is an auditory learner, needing to be in class to hear the lessons. Therefore, in order to support his learning experience, I created relevant lessons that could entice Zach to class. Through the use of controversial issues, technology, and current events, he connected chemistry with his own interests, and both his performance and class attendance improved.

In Activity 1, Zach revealed his understanding of how his family's contribution to the high $CO_2$ output problem was connected to his own interests stating "many things are left plugged in. . . [my family did] not turn anything off," and then later making the comments "maybe I want to get on twitter. . . and I am on there for two hours. . . or [I am] inside playing video games or watching TV." He further demonstrated this connection to his own interests as a baseball player when he described his family solution to $CO_2$ production problem- "lower the prices [by] staying outside and being active." In an effort to connect to Zach's interests, I paired him with a senior baseball player who could serve as a mentor as they wrote their analysis essays for Activity 3, therefore preventing him from missing class or shying away from the difficult task.

In each featured activity, I selected unique instructional resources to support students' learning by using relevant topics or personal interests. Activity 1 embedded my students' learning of the factor-label method in a personal experiment on energy conservation using data provided by an actual NASA engineer. Because my school enjoys good parent support, I had little reservations about asking my students to continue their learning by performing a home experiment. Education is enhanced whenever a partnership between school and home can be established. This activity played a perfect role using their homes to bring relevancy to a concept so deeply embedded in math technique that is often disliked by students.

Because most of my students are mid-low to high level students, I designed Activity 2 as an inquiry activity taking advantage of technology to engage curiosity and activate a higher thinking level. After observing how students responded to technology in Activity 2, my students used the GO app on the IPads to guide them through analytical writing, making the essay more attractive.

I chose two distinct types of students to display growth and understanding. Lauren, while a representative of a typical "A" student, is also very social and allows other students to distract her. Her work concerning NOS and her writing demonstrates a significant depth of growth from Activity 1 to Activity 3. Zach, Student B, is quiet, displaying very different personality and learning traits than Lauren. Zach doesn't willingly ask questions, mostly showing a lackadaisical attitude. He missed the first 2 days of introductory NOS discussion because he enrolled in the class late. I chose Zach because he demonstrates a growth in his NOS knowledge and his efforts in his classwork even though he approaches his scholastic efforts very differently than Lauren.

The assessment and feedback illustrated in Lauren's and Zach's work came through rubrics, completion grades, and assignment corrections. For Activities 2 and 3, rubrics were provided to students when each assignment was given. On all three I provided feedback through corrections on the paper and comments on the rubric. Activity 3 also included a peer-review day due to my students' weak writing skills. Activity 2 was only assessed based on completion of the assignment because my concern was thought process, not accuracy. I did not want worries concerning accuracy to hinder the inquiry process. During my informal assessments, I found areas where the students had not yet reached the expected level of competency, and I would tailor additional discussions, leading students to a higher level of mastery.

The activities are carefully sequenced to build upon one another, and students deepened their knowledge through each activity moving from reflection to discussion to analysis. For instance, Activity 1 asked students to reflect on NOS throughout their experiment. Building on that knowledge of NOS, Activity 2 asked students to apply their growing comprehension of NOS to historic experiments in a discussion essay. After assessing weak areas of students, Activity 3 then asked students to compose an analytical essay connecting a current event article with an assigned aspect of NOS, requiring them to revisit a weak area and strengthen it with application.

Lauren reveals growth in this process in very distinctive ways. In Activity 1, she illustrated basic understanding of NOS concepts by demonstrating her ability to recall definitions when she defines observation and provides specific examples of observation in her experiment- "I used the sense of sight . . . I checked my kWh every day." However, she reveals a grave misconception when she explains that science is partially subjective when "my [kWh] numbers weren't the same," instead of connecting this occurrence to the experimental design process.

Lauren shows a growing NOS understanding in Activity 2 by providing good definitions and stronger applications in discussion. For instance, in paragraph 2 she defines inference correctly and then connects inference to the varying atomic models. She does the same in paragraph 3 for the idea that science is subject to change. However, she remains weak at providing strong explanations and links to the experiments. She never answers the question "**why**" for varying models or "**why**" science is changing. As a result, while her application is improving by providing accurate definitions and examples, her depth of understanding is still weak.

In the final activity, Lauren shows she has strengthened her previously weak explanations through deepening her understanding of NOS concepts. She initially demonstrates growth by accurately indentifying most of the NOS aspects in part I. She even correctly identifies the scenario that exemplifies science as partially subjective (showing growth from Activity 1). As she moved to the analytical essay, Lauren showed improvement in both of her previous weaknesses- her misconception of partially subjective and her weakness at explaining "**why**." For example, Lauren ends her third paragraph by stating, "Telling the opinions as if they were factual is proving that science is sometimes based on bias. The scientists are disagreeing based on what they believe to be true and false." In this example, she correctly defines the idea that science is partially subjective and explains **why** and **how** it is seen in the article.

At the same time, Zach also demonstrates great growth in understanding but in different ways. In the first activity, Zach was still playing catch-up from his late sign up, including the NOS discussion that he missed. His journals reveal a very elementary knowledge of the subject. In fact, he actually does not follow the directions to reflect on only **one** aspect of NOS. He chose instead to discuss all seven aspects which actually seems to indicate that he does not understand the concepts well enough to choose just one aspect to explain.

Zach's understanding and explanation of NOS improve in Activity 2. He focused on one aspect for an entire paragraph, providing solid explanations. In Activity 1, the majority of his journals jump from one aspect to another in a paragraph with vague examples. In Activity 2, he focused on observation and its derived knowledge in two paragraphs giving solid examples. However, some of his examples did not apply to the simulation, and he demonstrated a distinct misunderstanding in the 2nd paragraph concerning the idea that science is subject to change.

In the 3rd activity, Zach's misunderstandings continue to wane, and he demonstrates a growing depth of knowledge. In part I of the activity, Zach accurately connects more NOS aspects to scenarios than his 1st activity when his examples were indirectly related at best. In fact, he improves his understanding of the difference between experimental design and science changing by correctly identifying and explaining scenarios 1, 3, and 6. Although he incorrectly identified scenario 7 as scientific thought changing that was easily addressed in class. As a result, his analytical essay focused on the 2nd concept he demonstrated misgivings in- science being socially and culturally embedded. In his analytical essay, he successfully explained the aspect, provided specific examples of the aspect in the article, and kept his discussion on topic. His statement, "A connection between the article and science is socially and culturally embedded is that Congress is involved in this project because they are the ones controlling the remaining of the process," is a perfect example of his improvement in understanding and explanation.

Reflection

Overall, I would consider my instructional sequence for teaching NOS over time a success as an integrated piece of a chemistry unit. The majority of my students demonstrated growth in

NOS understanding and in chemistry concepts. The topic challenged the prior thoughts and ideas of my top students and provided relevance for those students taking the class for graduation. Looking back, I would alter the design of two activities in the sequence because they did not work quite like I desired. The initial agree/disagree activity I used to assess prior knowledge of NOS really did not give me a clear picture of their misconceptions and gaps in knowledge. In the future, I will ask students to explain why they chose their answer because I found that writing reveals a much better picture of their thought process.

The second activity I would change is actually the 4 week home energy project my students conducted. The project was graded like a cumulative test and didn't post in the grade book until the end. I graded items as they came in and students earned points toward a 75 point test grade but did not receive intermediate grades. As I got to know these particular students, I found that many of them did not grasp the significance of participating in the sequential individual components of the project until it was too late. As a result, if I could redo this assignment with this group of students, I would segment the project and treat each piece as a quiz grade so students could see the significance of the project and would keep them focused along the way.

Aside from these two minor problems, the sequence of instruction successfully advanced my students' understandings and achieved the goals I had created for the unit. For example, one of my major goals of the unit was to create a deep understanding in my students of how NOS affects their life. Activity 1 addressed this goal in particular. My students came face to face with the problem of convincing their family to give-up cultural norms to conserve energy. Even more significant, Lauren and Zach each displayed personal growth in understanding by applying an aspect of NOS. Lauren began the unit with a misconception concerning science's partial subjectivity and ended the unit with an excellent analysis of partial subjectivity and the Mona

Lisa. Zach displayed a misunderstanding of what it means for science to be socially and culturally embedded and provided excellent analysis of science and society meeting in his analysis essay.

Another major goal of the unit was to improve decision making skills through honing their observation and inference skills. Activity 1 achieved this goal by asking the students to use the skills; then, in Activity 2, they applied these skills in an inquiry investigation. The final goal of the unit was to create engaging and relevant lessons for chemistry topics. I made it relevant through the use of technology- power meters, simulations, and iPads. Activity 3 engaged students by encouraging them to see NOS application in current event articles about their interests. While Activity 1 brought relevance to unit conversions by having students apply the concept to their home's production of $CO_2$. Zach even connected this production to his use of twitter and video games.

My culminating assessment proved to be very useful in illustrating my students' understanding of the major idea. By breaking the assessment into two parts- a review of all the aspects on NOS and then an analytical essay- I was able to first identify any lingering misconceptions and then have the students focus on that misconception in a final essay. By providing students with the "Drawing Conclusions" GO, I was able to ascertain any lingering misconception before having them attempt to write about NOS. By requiring my students to write an analysis essay as opposed to taking a typical paper test, I received greater insight into their true understanding of the NOS aspect because they had to first understand the idea behind the aspect and then apply it to a real life current event. This moved them from memorization and into deep understanding and therefore revealed a broader picture of their overall understanding of the major idea.