Project Title: The Clean Water Project

School: Research Triangle High School, Durham NC 27709

Grade Level: 10th

Your Name: Monica I. Strada

Project Partners: Jane E. Disney, PhD. and Hannah Lust PhD.

Teacher/Scientist Partner Profile: This was my 19th year of teaching, 4th year in North Carolina at Research Triangle High School. I hold an undergraduate degree in Chemistry from the University of Toronto, a Master of Arts in Teaching from Sacred Heart University. I am passionate about bringing authentic, real-world science experiences to high school students, and participating in this project was a great fit for my teaching practice. All About Arsenic was of particular interest because I had recently helped develop an arsenic-focused curriculum for high school teachers with the University of North Carolina's Superfund Research Program, drawing from North Carolina's existing private well contamination. I was piloting this K-12 project in North Carolina with the goal of informing a broader rollout for similar programming in collaboration with UNC's existing community-based well testing.

Summary: This project was embedded in an accelerated, 10th grade Chemistry course called "Investigative Chemistry". In this class, students study chemistry in a project-based learning format, in which they are taught to read/interpret primary source literature, develop research questions and testable hypotheses, conduct experiments, analyze data, and present their findings. As such, the All About Arsenic citizen science initative was a good fit for my existing "Clean Water Project", which I adapted this year to incorporation the analysis of water samples and frame from the perspective of arsenic contamination of private wells. To build student skills and successful engagement with the required data analysis, Tuva was introduced in the fall of 2021 to explore graphing choices and basic statistical analysis. Established Tuva programs used included "The Story of Half-Lives and Isotopes", "How Have the Sales of Electronic Devices and Appliances Affected Mining of Earth Minerals" and "Trends in the Table: Size and Ionization Energy". Students also did several literature reviews in the fall to inform classroom cell phone policy and their experimentation with tea. These activities provided a framework for the eventual deep dive into arsenic contamination of water in North Carolina. Solicitation of well water samples from the school community began in early October, with samples set to Dartmouth for analysis in both November and February. Students then started the Clean Water Project in March, in which they broadly explored the following questions:

- How does arsenic impact human health?
- How do heavy metal contaminants enter drinking water?
- How can chemicals in the ecosystem be quantified?
- How are contaminants removed from water?
- How is the environmental toxicity of a contaminant evaluated?

These questions were embedded in a sequence of project "checkpoints", outlined and linked below. Checkpoints included a literature review "case study" looking at heavy metal contamination in North Carolina and beyond, drawing from the work of local researchers at UNC. Students then analyzed the well water samples collected at Research Triangle High School, asking questions about the data sets found in Anecdata and Tuva. First students explored the large New England dataset, and then look at the must smaller dataset from North Carolina. They also investigated an ArcGIS map built from soil, water and geology data specific to North Carolina, drawn from the work of Superfund researchers. Students then reviewed how to quantify chemicals in the environment, exploring mole concepts, molarity, conversions, and reaction stoichiometry. Removing contaminants followed, where students practiced chemically removing heavy metals from a model

system using precipitation reactions and tested the efficacy of different types of pitcher filters. In the last checkpoint, students did a bioassay with duckweed using a contamination water model system. The final product was to create an "Inform the Public" piece that integrated checkpoint work and provided an evidence-based outreach presentation to share with the broader school community.

Project Details:
Number of Student Participants: 15 students were involved in this project
Number of Water Samples Collected: 15 samples analyzed (16 collected)

Curricular Materials:
The Clean Water Project Overview 2021-2022
In 2022, one in four people will not have access to safe drinking water (OWID). Thus globally, lack of clean drinking water is considered one of the world's largest environmental health problems. It is estimated that unsafe water is responsible for 1.2 millions deaths each year. While many consider clean water access to be a problem in the developing world, here in the United States contaminated drinking water continues to be a problem in some communities. In this project, you will investigate contaminants in drinking water through existing data sets from both North Carolina and New England, and analyze well water data collected from the RTHS community through the Citizen Science project "All About Arsenic". You will create a PSA (a poster, short video, pamphlet) to inform the public about inorganic arsenic in drinking water using the well sampling results and concepts explored in this project.

- **Checkpoint 1**: Case Studies
  - How do heavy metal contaminants enter drinking water? Focus on selected research from UNC-Chapel Hill.
  - What are the implications for human health?
- **Checkpoint 2**: TUVA: Asking Questions about Drinking Water
  - What questions can we ask? What questions can be potentially answered by this data set? What information do we need to further investigate these questions?
  - Analysis of New England and RTHS well water data; observations, points of interest, possible conclusions
- **Checkpoint 3:** Chemical Quantities
  - The Mole, Empirical and Molecular Formulas
  - Basic Mole Conversions (mass/particles/volume)
  - Reaction Stoichiometry
- **Checkpoint 4:** Removing Contaminants from Water
  - Using precipitation reactions to remove contaminants from an Fe-based model system
  - Implementation of reaction stoichiometry, theoretical and actual yields, purity
  - Testing pitcher filtration with Fe-based model system (Zero Water, Brita and Amazon special); discussion of limitations
- **Checkpoint 5:** Evaluating Environmental Toxicity
  - Determine the toxicity of model system on duckweed, analyze and report data
- **Final Product**: Inform the Public
  - Integration of checkpoint work to inform the public about the dangers of arsenic in drinking water; student choice on medium and type of presentation; may include video, slideshow, poster, etc.

Collaboration: While the intent of this project was to collaborate with two other chemistry teachers, when it came time to run the project neither individual chose to participate since they were new to the school and behind in the curriculum.

Field Trips: There were no field trips associate with this project.

Experiments: Students conducted three sets of experiments. In the "Removing Contaminants from Water" checkpoint, students first explored whether simple precipitation (double replacement) reactions could be used to remove iron from our Fe-based model system. Second, they tried using water pitcher filtration to remove iron, testing for its presence both visually and with test strips. Finally, students did a bioassay with duckweed using the contaminated water system in "Evaluating Environmental Toxicity".

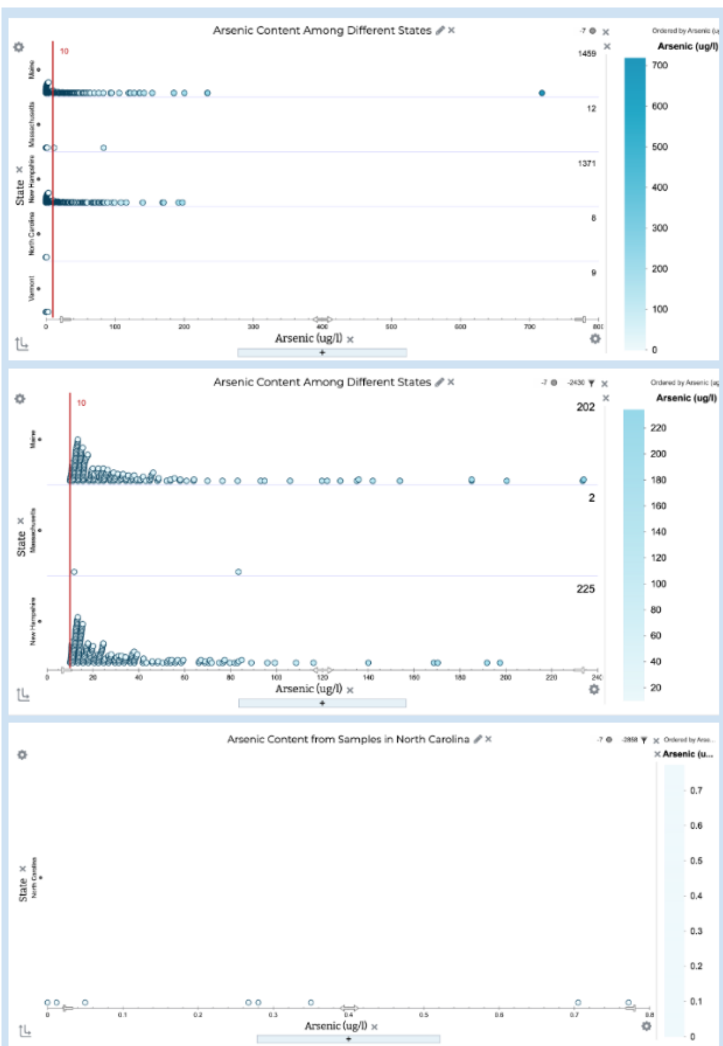
Stipend Expenditures: The stipend was used to pay for shipping costs for the water samples to Dartmouth. Other materials were available in the school.

Guest Speakers: We had several guests join our classroom to discuss different facets of arsenic contamination of drinking water:

- Dr. Andrew George (UNC) – Community Well Testing in North Carolina
- Dr. Hannah Lust (MDIBL) – Mining Anecdata & Tuva Analysis
- Dr. Lauren Eaves (UNC) – Inorganic Arsenic in North Carolina, a 20-year study

Tuva Usage: Tuva was used both in fall projects to explore the platform and introduce chemistry concepts. It was also used extensively in the Clean Water Project to ask questions about both New England and North Carolina datasets. Please see student work samples below.

Sample student work: How do the different arsenic levels in water differ between different states?



Looking at this data, I can conclude that New Hampshire has the highest number of samples containing toxic levels of arsenic out of the states where samples were taken. Looking at the graphs I created, I first plotted all the samples on the chart by state and arsenic level, then removed any samples with an arsenic level below 10 ug/l, the maximum allowed content in drinking water, to look at the samples which contained toxic levels of arsenic. From these graphs, I found that 202 samples (plus an outlier I needed to remove to visualize the graph) from Maine contained toxic levels of arsenic or about 13.9% of the total samples in that state, Massachusetts had 2 samples or 16.7%, and New Hampshire had 225 samples or 16.4%. While Massachusetts had a higher percentage of samples with toxic arsenic content, not many samples were taken from that state and so this data is not very representative of the whole state. Since New Hampshire had the largest amount of toxic samples and the second-highest percentage out of the total samples in that state, I concluded that New Hampshire likely has a higher arsenic content in many of its wells than in the other states.

Comparatively, when looking at the data from North Carolina, there are not many samples collected and none of them contain high levels of arsenic. The highest arsenic level among these samples was 0.772 ug/l, well below the 10 ug/l state limit for drinking water. However, this is likely not representative of the state as a whole, as there are only eight samples taken. I did however find it interesting that the arsenic levels in the samples from North Carolina were significantly lower than the samples from other states, particularly Maine and New Hampshire, and this variance could likely do with geographical location and the amount of arsenic content in the soils of North Carolina versus Maine or New Hampshire.

Community Outreach: The final product for the Clean Water Project was to create an "Inform the Public" presentation, where students were challenged to incorporate the data and analysis from the project checkpoints into a piece that communicated their findings. Students were given a choice of medium, and while some did classic presentations, others created posters or a video. The following are samples of student work: Sample 1: Poster; Sample 2: "spoof" video; Sample 3: presentation.

Discussion:

Overall student engagement was very high in this project. Students were excited to participate in community-based research and know that they were part of a larger project that was also going on in New England. The guest speakers were fantastic and really enhanced this work.

> Student to Dr. George: *"I have learned a lot about your work as well as the issue with environmental justice and how contaminated our water can be. Thank you for working with our communities in North Carolina to help better their water supply and wellbeing! Much Appreciated, thank you."*
>
> Students to Dr. Lust: *"Thank you for teaching us about how to look closer at, and fairly interpret data"* and *"Thank you very much for coming to speak to us the other day. I was surprised to learn how much we could do with the Tuva software".*
>
> Student to Dr. Eaves: *"Thank you so much for coming in and talking to us about metal contamination in water. It was really informative. I wish we'd had more time! You are a fantastic speaker."*

One of the big challenges was collecting well water samples in my school community, where most students live in cities such as Durham and Raleigh, and are therefore on municipal water. The decision was made to solicit the school community as a whole for samples, and that yielded only 16 samples. For future iternations of this project, it would be helpful to partner with more rural counties or existing community well testing projects to yield a higher number of water samples.

The experimental portion of this work had mixed results. While students were able to successfully remove iron from our model system with precipitation reactions, the pitcher tests were not as successful, presumably because the filters are not designed for iron filtration. However, this yielded some interested discussions on the limitations of a model system, and how to approach this type of experiment in the future. The bioassay was a failure due to the lighting in our grow boxes scorching the plants due to their proximity. The assay was also conducted over a long weekend, with less time to check on the samples. Future iterations of this experiment need a full week of class time to monitor duckweed in more favorable growing environment. Student final products were mixed in their quality. While some were very good and thoughtful, others were less so, and missed communicating the data that was analyzed and collected. This suggests better oversight and communication from the teacher in future years, in addition to providing students with strong exemplars to clarify the project expectations.

Conclusion:

Overall this project was a great way engage students in both citizen science and data analysis. The adaptation of my existing Clean Water Project to this arsenic-focused citizen science project went well, however some activities could be better streamlined to tighten up the timeline for the project. Collecting a larger number of well water samples would be beneficial to yield data that can be better extrapolated to the greater community in our region.

References:

- A. P., Desrosiers, T. A., Warren, J. L., Herring, A. H., Enright, D., Olshan, A. F., ... & Fry, R. C. (2014). Association between arsenic, cadmium, manganese, and lead levels in private wells and birth defects prevalence in North Carolina: a semi-ecologic study. *BMC Public Health*, *14*(1), 1-12.
- Eaves, L. A., Keil, A. P., Rager, J. E., George, A., & Fry, R. C. (2022). Analysis of the novel NCWELL database highlights two decades of co-occurrence of toxic metals in North Carolina private well water: Public health and environmental justice implications. *Science of The Total Environment*, *812*, 151479.
- Sanders, A. P., Messier, K. P., Shehee, M., Rudo, K., Serre, M. L., & Fry, R. C. (2012). Arsenic in North Carolina: public health implications. *Environment international*, *38*(1), 10-16.
- Wasserman, G. A., Liu, X., LoIacono, N. J., Kline, J., Factor-Litvak, P., van Geen, A., ... & Graziano, J. H. (2014). A cross-sectional study of well water arsenic and child IQ in Maine schoolchildren. *Environmental Health*, *13*(1), 1-10.
- Yosim, A., Bailey, K., & Fry, R. C. (2015). Arsenic, the" King of Poisons," in food and water: levels of this poisonous element can far exceed the US Environmental Protection Agency's water standards in common foods such as rice. *American Scientist*, *103*(1), 34-42.

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