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Original Paper

Making it RAIN: Using Remotely Accessible Instruments in Nanotechnology to Enhance High School Science Courses

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Abstract

The Remotely Accessible Instruments in Nanotechnology (RAIN) Network is a conglomerate of nineteen community colleges, four-year universities and high school sites that aims to enhance STEM learning by bringing advanced technologies to K-12 education. RAIN provides free remote access to instruments such as Scanning Electron, Atomic Force and Transmission Electron Microscopes, as well as Energy Dispersive and Infrared Spectroscopy. The following is a variety of experiments and an empirical formula lab that can be performed in a high school physical science or chemistry classroom that utilizes the RAIN Network.

Keywords

remote instrumentation, chemistry, Scanning Electron Microscope

1. Introduction

With the advancement in electronics, students have become dependent, and in many instances, addicted to their technology (Kardefelt-Winther, 2017). This technological evolution opens the door for educators to infuse novel technologies into their curriculum. Currently, virtual labs (Hovardas, 2017) and interactive science simulations (Moore, 2014) have shown positive impact on student learning. The next phase in technology inclusion in education is to move from contrived virtual labs and simulations to using web-based streaming remote instrumentation, which allow students to image and analyze laboratory specimens in ways previously inaccessible in the high school science classroom. This is the goal of the Remotely Accessible Instruments in Nanotechnology (RAIN) Network. Not to use technology for technology sake, but to provide an interactive community, wherein students can obtain experimental data remotely over the internet, while interacting with scientist across the country.

The RAIN Network aims to provide educational sustenance to scholars across the globe. Previous RAIN studies have highlighted the impact access to technology can have in classrooms where resources may be limited and connections to science careers may be sparse (Ashcroft, 2018). Thus, the aim of the RAIN network is to supply all educational levels free access to advanced technologies in every socioeconomic academic community (Figure 1). Students in urban Los Angeles to rural New Mexico can be afforded the same access to complex, and interesting scientific tools, needing nothing more than an internet connection.

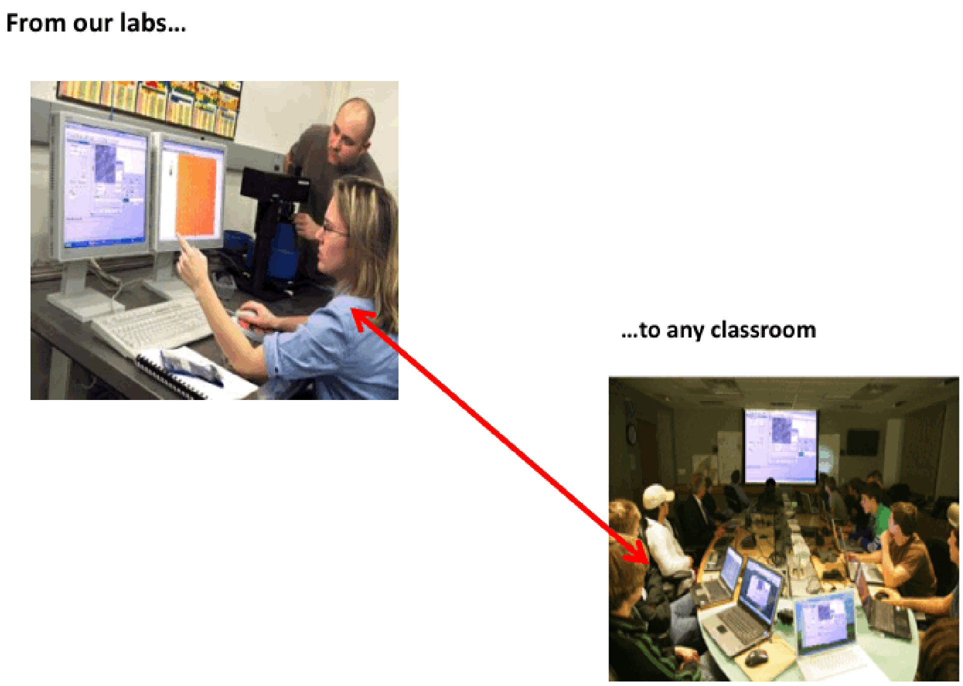

Figure 1. Bringing RAIN to Your Class

The RAIN Network consists of nineteen sites (Figure 2), ranging from four year, tier 1 research institutions, such as Stanford University, to technical colleges like Northcentral Tech and even Cattaraugus-Allegany-Erie-Wyoming Board of Cooperative Educational Services (CABOCES), a high school program in upstate New York. The mission of RAIN is to lower the barrier-to-entry for instructors to deliver authentic and relevant educational activities for students interested in STEM education. One focus of RAIN is to bring technology to institutions in communities with substantial underrepresented student populations, specifically African-American and Latino communities, where access to our instruments could be the path for many to see a science education where it did not seem possible before.

An empirical formula lab that can utilize the RAIN Network to enhance a classic high school chemistry experiment is communicated. Student and teacher feedback will be presented, extolling the positive influence RAIN had on their educational experience. Finally, high school educators are given examples of RAIN used in other science disciplines through science education literature, as well as from the RAIN Network library. Students are also extended an invitation to utilize the RAIN Network on an individual basis for Science Fair experiments.

Figure 2. RAIN Sites across the United States

2. Getting Started

The most compelling advantage of RAIN is how easily it can be implemented in high school science classrooms. RAIN scientists have performed dial-ins to over 100 academic sites, including twenty-seven K-12 classrooms (5-10th grades). In each instance, the teacher had a computer, projector and connection to the internet, the only necessities needed to implement RAIN. In all but one classroom, students also had access to computers for their own use, which can allow students to control the instruments themselves. In total, the RAIN experience can be performed in under an hour, thirty minutes dedicated to teacher preparation ahead of the remote session plus thirty minutes of in class time. Imagine being a high school student, live-imaging the gap between nanostructures in a butterfly wing or the setae on a gecko's foot. With facile implementation, little time commitment and no cost, the benefit of exploring using the RAIN Network is vast.

A RAIN session can easily be set up by going to the Nano4me website at http://nano4me.org/remoteaccess. Under the heading "Getting Ready for Remote Access" a step-by-step sequence of events to get started is described. The only software that must be downloaded onto your computer is "Zoom", an online meeting space similar to Skype, that also allows for teachers and students to remotely control the instrument. Zoom and all sessions are freely available at https://zoom.us/.

Out of the 27 remote sessions to K-12 classrooms, only one had connection problems. This was not the fault of technical issues, but of one RAIN site miscommunicating time zones with the high school teacher. Since RAIN has sites across the country, it is imperative that you communicate directly with the RAIN site you choose to set up the remote session. In every instance in which the test session was performed, the RAIN session commenced smoothly.

3. Updating Classic Empirical Formula Experiments in Chemistry

Empirical formulas are the simplest positive integer ratios of atoms in a compound. Performing empirical formula calculation are beneficial in helping students understand mass to mole conversions, as well as molar ratios. There are several classic empirical formula labs that have been utilized in assisting students understanding of this topic. The RAIN Network was utilized to enhance the experience students have when performing these experiments. Two different empirical formulas were investigated using magnesium and iron oxidations. Each oxidation reaction was done in lab, followed by empirical formula determinations using mass differentiations and elemental mass percent obtained via RAIN's Scanning Electron Microscope (SEM) with Energy Dispersive X-Ray Spectroscopy (EDS) technology.

When a magnesium ribbon is oxidized by oxygen, magnesium oxide forms (**Reaction 1**). This reaction has been used in chemistry laboratories to study empirical formulas by differentiating the mass of magnesium before and after oxidation.

$$2\ Mg_{(s)} \ + \ O_{2(g)} \ \rightarrow \ 2\ MgO_{(s)} \quad \textbf{(Rxn 1)}$$

A detailed explanation, safety precautions and sample calculations of the experiment can be found (Nguyen, 2012). To better engage students with this experiment, the RAIN Network was used to image and perform elemental analysis of the magnesium before and after oxidation (Figure 3), allowing students to visualize a concept that would otherwise be purely theoretical. Students connected to the RAIN Network and after SEM imaging of the samples, used EDS to determine the percent mass of each element in the sample. EDS is an analytical technique based on the unique atomic structure of an element and the elements interaction with x-rays that lead to a distinctive electromagnetic emission spectrum, allowing for elemental analysis, including elemental mass percent. One benefit of RAIN is that during the analysis of samples, students may interact with scientist running the instrument, many of whom have doctorates in chemistry, allowing for an explanation on EDS. This is an ideal scenario, where students can be reintroduced to quantum theory topics, discuss electron excitation and emission, and the theory behind how EDS works. Therefore, students not only learn the theory behind the mechanisms of this chemical phenomenon but they also learn the theory behind the technology.

During one lab, as a student was observing the magnesium oxide product, the question was asked "How do we know the product is magnesium oxide?" She was looking at the ashy product and trying to justify the conclusion that indeed the product is MgO. As science teachers, it is imperative that correct scientific analysis is followed. Even though this is a well-known, characterized reaction, it will be the first-time students are performing it. Good research practice teaches that verifying results with multiple experiments or characterization methods is essential for development of accurate conclusions. Using RAIN elemental analysis not only allows for the percent mass to be determined, but also allows students to visually confirm that it is actually oxygen that combines with magnesium in this process. In Figure 3**,** the magnesium image has a crosshair in the middle. This is the point at which analysis occurs (it is possible to analyze over the entire image). In the image of MgO, it clearly shows that indeed oxygen has been combined with magnesium to form the MgO product. It was also possible to see that in the product some nitrogen was present (asterisk on EDS spectrum). Formation of magnesium nitride (Mg_3N_2) is a common outcome in this reaction and the EDS provides a method of analyzing this side product that occurs in this process. Using the percent mass values, the empirical value obtained through mass differences can also be confirmed using proper mass percent to gram to mole conversions.

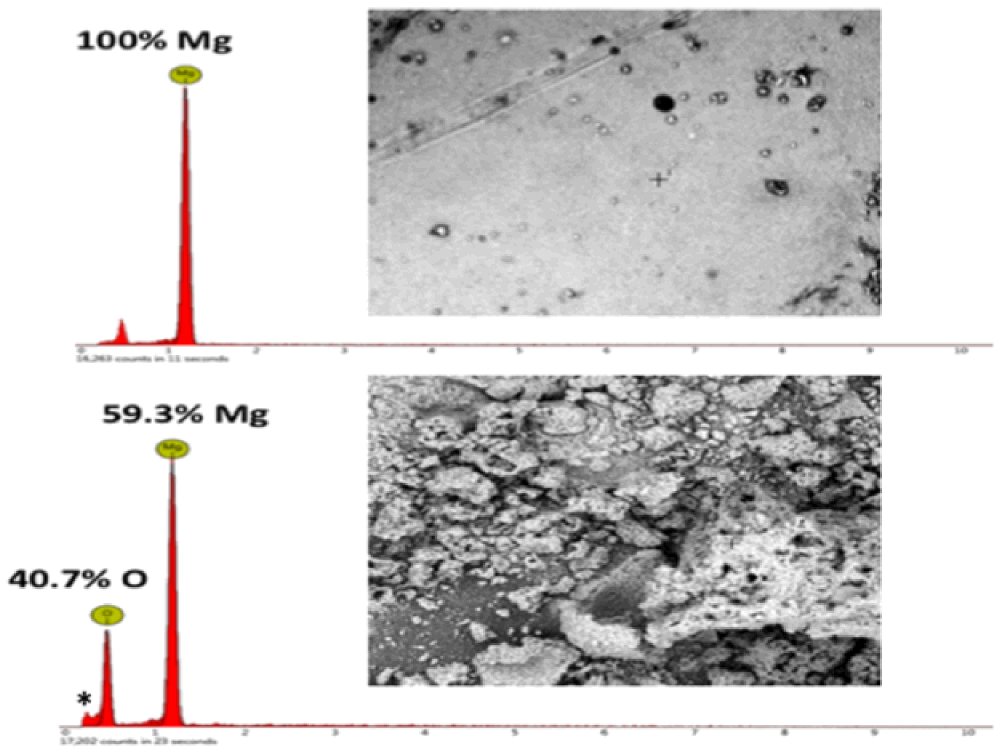

Figure 3. SEM image of Top Magnesium Ribbon Bottom Magnesium Oxide

The magnesium oxide empirical formula experiment is used in chemistry classes due to how successful the reaction works in giving the correct 1:1 molar ratio of magnesium to oxygen. A second empirical formula reaction was performed using steel wool (iron) to react with oxygen to form an iron oxide (Ashcroft, 2018; **Reaction 2**).

$$4\ Fe_{(s)} + 3\ O_{2(g)} \rightarrow 2\ Fe_2O_{3(s)} \qquad \textbf{(Rxn 2)}$$

In this experiment, the mass of steel wool is determined, then washed in acetone, dried, followed by dipping into 0.1 M acetic acid and dried again. The reaction is performed in a test tube inverted in water and as oxygen is consumed, the iron oxide (rust) forms, with water displacement into the test tube. At completion of the reaction, the mass of the oxidized steel wool is determined and by subtracting original steel wool mass, the oxygen content in the iron oxide is determined. Finally, the empirical formula is calculated using mass to mole conversions and molar ratios. In this case, the masses will not lead to the 2:3 molar ratio of iron to oxygen due to oxygen being the limiting reagent. Though obtaining the correct answer should not be the overall goal of an experiment (going through the scientific method should be), this particular empirical formula determination is not satisfactory to students and teachers because of the non-sensical answer achieved.

When the elemental analysis is used from the RAIN Network it is possible to image iron that has been completely oxidized by the oxygen, giving the correct mass percent 69.5% iron and 30.5% oxygen that leads to the correct empirical formula of Fe_2O_3. In this case, the RAIN Network has provided data that can assist in formulating a conclusion to an experiment that was not possible before. It also allows for a discussion about comparing the two reactions and why one gave the correct empirical formula and the other did not. Students were assessed for these labs using the following prompt:

> Write a mini-lab report that consists of a concise abstract, shows complete calculations of empirical formulas and has a conclusion that makes a conclusive statement about the empirical formulas determined and use your data to compare and contrast the two oxidation reactions that were used to determine empirical formulas.

The following rubric consists of two components. A summative assessment assessing if students successfully calculated the empirical formula and a formative assessment that assesses students understanding of the two experiments based on their conclusion:

	4-Exceeds Criteria	3-Meets Criteria	2-Progressing to Criteria	1-Below Expectations
Empirical Formula Calculations	Students Correctly determine empirical formula using reaction masses and SEM analysis.	Students can correctly determine empirical formula using either reaction masses or SEM analysis.	Students are able to determine moles of magnesium and oxygen but cannot relate to empirical formula.	Students are unable to perform any calculations to determine empirical

				formulas.
Analysis/ Conclusion	Students write a conclusive statement and discuss the two methods of determining empirical formula for both magnesium and iron, emphasizing that EDS is preferred for iron oxide analysis due to oxygen being the limiting reagent, whereas in the magnesium oxide reaction both EDS and mass analysis are effective due to magnesium being the limiting reagent. Nitrogen as Mg_3N_2 side product is also discussed.	Students write a conclusive statement and discuss that both methods in the magnesium oxidation give valid results and that the EDS analysis confirms results from the mass analysis. No comparison to the iron experiment or mentioning that oxygen is the limiting reagent in the iron reaction. Also, nitrogen as Mg_3N_2 side product not discussed.	Students write a conclusive statement, but there is no comparison of the two experiments or discussion about benefits of EDS analysis. No mention that the oxygen is the limiting reagent when reacted with iron or that nitrogen as Mg_3N_2 side product forms in the magnesium oxidation.	Students do not write a conclusive statement.

When performed in a high school chemistry class 80% of students were able to correctly perform empirical formula calculations after the experiment and achieved a 3 or 4 on the calculation assessment. However, when assessing the analysis and conclusion, only 6 out of 29 students were able to achieve a 4, with over half of them achieving only a 1 or 2 score. The experiment was performed before discussion on limiting reactant. Therefore, for better results on the analysis assessment, having the limiting reactant discussion before performing this experiment is ideal.

4. Classroom Setup

The experimental set-up for the empirical formula with RAIN can be done in various ways. If a teacher wants to use RAIN as a "demo", students can perform the two oxidation reactions as the teacher connects with RAIN using Zoom. Connecting to RAIN is easy and takes less than five minutes. For most efficient time, perform the magnesium oxidation first, a reaction that took high school students about thirty minutes to complete, and then set up the iron oxidation. Student samples can be sent directly to RAIN for imaging. However, for the empirical formula experiment each RAIN site will have samples prepared using the lab procedures. Having students image their own sample is preferred and RAIN encourages the students to send their samples and arrange a one-on-one experience. This is the most impactful aspect of RAIN. How often do high school science students have an opportunity to talk science experimentation with professors at universities?

The iron oxidation takes twenty minutes. During the twenty-minute wait, the remote session can take place, having the RAIN scientist give a short description on SEM/EDS theory, imaging the sample and performing the elemental analysis. This method does not allow students to control the instrument but is very efficient for collecting the data and giving students a glimpse into electron microscopy, a tool very few high school students have contact with.

A second option is to have students rotate through stations. Zoom can be logged into through multiple computers. If four computers are available, students can be performing the two experiments and rotate through the RAIN component. If four groups of two students are at each computer, it will allow for the RAIN technician to help students manipulate the instrument themselves. This is an ideal situation where students can be manipulating the instrument, while having a web-based question and answer session with the RAIN scientist. There is no limit on the amount of time RAIN will work with a class. It can be a quick twenty-minute demo, or a two-hour session aimed at working with individual students. It is up to the teacher to tell RAIN how they prefer to use the resource.

All that is required from the teacher is to download Zoom, attend a test session, which can be as little as five minutes or if the teacher wants to do a detailed plan with RAIN up to an hour and lastly log into Zoom during the in-class remote. At this point, RAIN scientist will discuss all aspects of using SEM/EDS for experimentation, allowing for teacher input to be added at any time. Seeing the excitement on students faces when they get to visualize microscopic images that they never have before is a payoff for what can amount to twenty minutes of in-class time.

5. Teacher Feedback

The RAIN Network has performed hundreds of remote sessions, but recently a study was performed to analyze its effect on students' interest in science in K-12 education using various problem-based activities and RAIN at K-12 schools consisting of predominately underrepresented student populations (Rodriguez, 2018). Twenty-seven teachers were surveyed in the study. Out of the twenty-seven, all of them felt the remote portion of the lab increased student engagement, twenty-five felt the remote access greatly contributed to the comprehension of the lab and twenty-two were very likely to use the remote access lessons in the future. Twenty-four of the teachers also said they would very likely recommend the remote access activities to colleagues. Figure 4 quantifies the value in using RAIN, where a five corresponds to positive impact. The value after the bar correlates to the average teacher response.

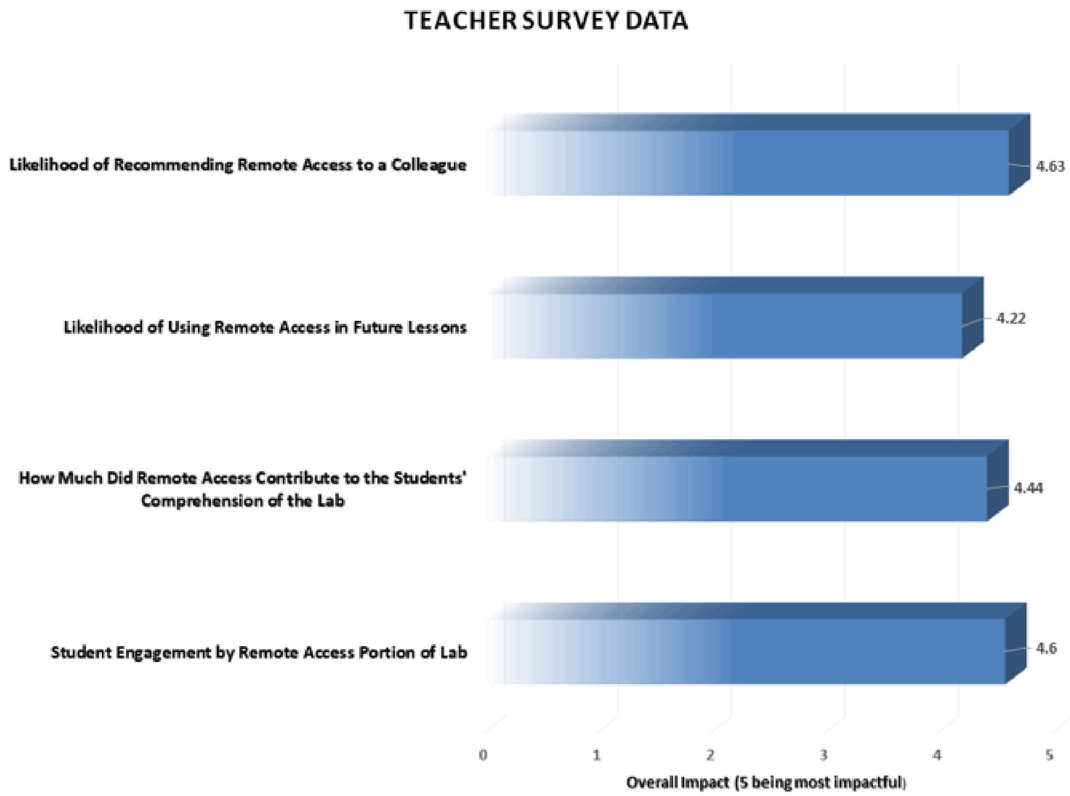

Figure 4. Quantifying the Impact of RAIN from Teacher Survey (n=27)

The study also assessed the biggest obstacles in student success in STEM according to teachers. Interestingly, access to technology at school was not a hindrance to student's success, showing the feasibility of implementing RAIN in classrooms organically. Of the biggest obstacles, exposure to real-life content was the highest obstacle described by teachers in teaching STEM. Access to remote technology and bringing the real-life content through innovative active learning activities to the high school classroom can alleviate this problem. The RAIN Network is currently working on experiments that will use active learning in conjunction with RAIN that will be provided as a freely available open education resource when completed.

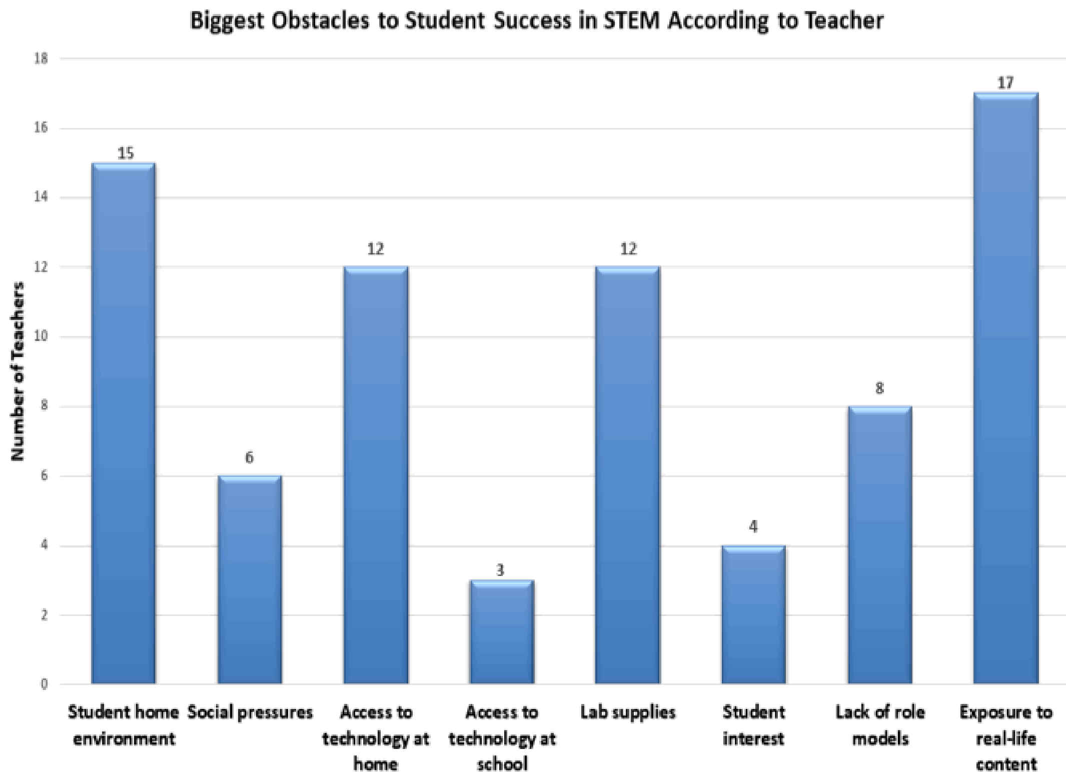

Figure 5. Biggest Obstacles for Student Success in STEM from Teacher Survey (n-27)

Several teachers gave feedback on using RAIN in their classrooms:

High School Chemistry Teacher: "Great learning opportunity! I want to try RAIN on my own now.

High School Physical Science Teacher: "This activity gave me an understanding of my students understanding of chemical reactions. This will be a great way to start my next unit on chemical reactions."

Middle School Teacher: "Thanks you so much! The presentations, labs and remote work with the scientist using the Scanning Electron Microscope were so engaging and educational. Thank you for inspiring students?"

6. Student Feedback

Positive feedback from teachers was a desirable aspect of RAIN, but more importantly has been the amount of interest seen by students when performing RAIN in the classroom. A year-long study on using RAIN in the K-12 classroom was performed and students were asked a series of questions about the interest and effectiveness of RAIN. Charts A and B in Figure 6 show that students enjoyed the RAIN sessions, while having a positive impact on their interest in science and that they would like to have more RAIN labs. These studies were performed in schools with majority underrepresented populations and it was noteworthy that the RAIN experience showed positive impact across all student demographics. In fact, after the RAIN session a 2.5-fold increase was seen from students in passion for science and interest in pursuing a career in science (Rodriguez, 2018).

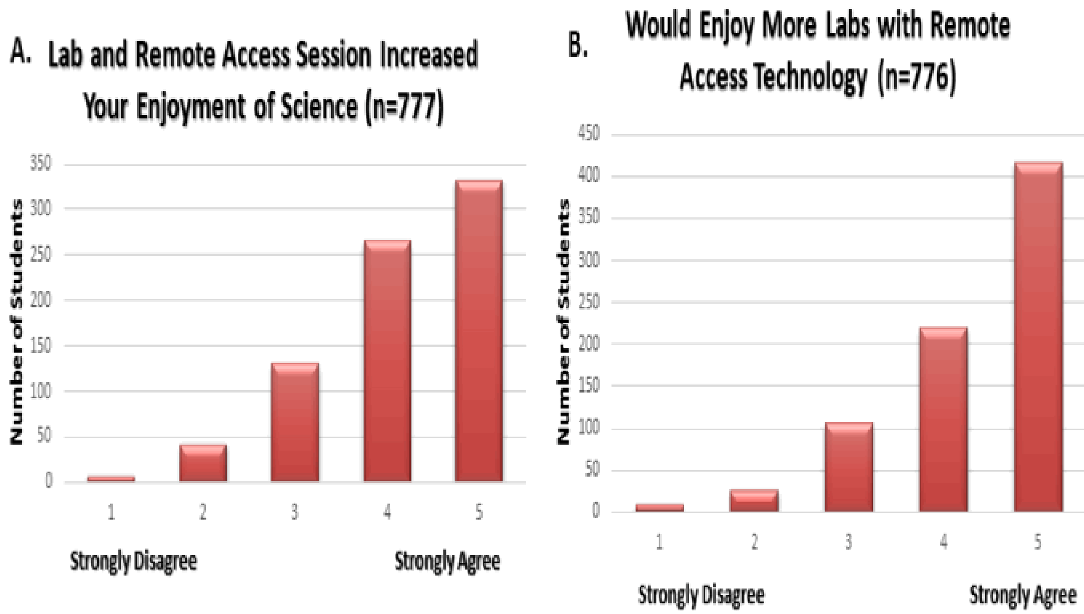

Figure 6. A. Student Enjoyment Using RAIN B. Students Desire for More RAIN Labs

More applicable to the empirical formula labs, when the data is sorted solely for high school students whom were asked if the remote session helped them understand the lab (Figure 7), almost 70% of students felt that using the remote access did indeed help in the understanding the experiment, with only a total of 18 students (7%) feeling like the RAIN session did not help. Though this data is subjective, it should not be discounted that students have been actively engaged, enjoyed and felt these RAIN sessions have enhanced their learning experience. We asked students for comments after the experience. After reading several "This is cool" or "I enjoyed this experience", two are apropos based on being from schools exclusively of underrepresented student populations that are from low socioeconomic areas as to why RAIN is a powerful educational tool:

10th Grade Physical Science Student: "Actually got to see through a microscope. I learned what a microscope is useful for. Didn't know before."

11th Grade Chemistry Student: "I enjoyed connecting with scientist from other schools. It was great meeting college students who are interested in science."

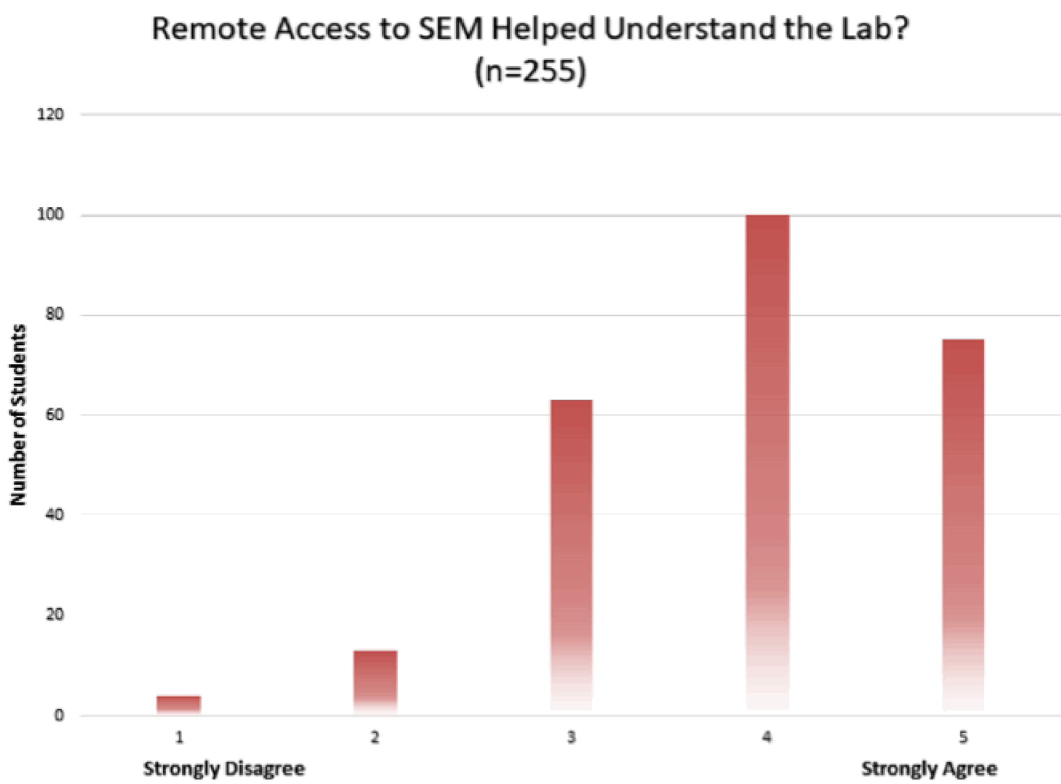

Figure 7. Increased Understanding of Empirical Formula Lab Using Remote Access

7. RAIN Extensions

There are several RAIN labs available on the Nano4me site, encompassing basic science principles, interdisciplinary and nano-based labs. There are also several published RAIN labs, including using Mars as a platform to teach about mineral identification (Rodriguez, 2018) and studying oxygen generation in space (Ashcroft, 2018). Furthermore, these labs come included with suggestions for implementation and differentiation for an array of grade levels or educational background.

The empirical formula experiment is aimed at introducing the RAIN Network to teachers and students. Students can contact the RAIN Network and utilize our instruments for science fair projects on an individual basis. During these sessions they may even talk with our scientist about their project. This would be a valuable resource in their research endeavors. Teachers can also inquire about joining the Nanotechnology Professional Development Partnership (NPDP) at nano4me.org/workshops, a web-based streaming service provided for educators interested in implementing RAIN, specifically nanotechnology-based experiments, into their high school curriculum.

8. Conclusion

People communicate differently today. With Facebook, Twitter, Instagram, Fortnite, and many more, students have become reliant and addicted to their technology. As teachers we need to progress in how we implement technology in our classrooms. If the most advanced technology students have access to in school is their cell phones, we will struggle keeping students interests. The RAIN Network is a cost-effective method to bring advanced technologies to all high school classrooms. This is most important in providing technology to schools from low socioeconomic schools, many of which contain majority underrepresented students, where students do not have the opportunity to experience complex science experimentation due to low funding and no access to scientific resources. Using the remote instrumentation in conjunction with scientific experimentation can keep students engaged in science. Allowing students to work on their own RAIN experiments or science fair projects will assist in developing a sense of ownership, leading to an increase in passion for the sciences and a higher likelihood of pursuing a science education.

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References

Kardefelt-Winther, D. (2017). How does the time children spend using technology impact their mental well-being, social relationships and physical activity? An evidence-focused literature review. In *Innocenti Discussion Papers* (No. 2017-02). UNICEF Office of Research—Innocenti, Florence.

Hovardas, T., Xenofontos, N. A., & Zacharia, Z. C. (2017). Using Virtual Labs in an Inquiry Context: The Effect of a Hypothesis Formulation Tool and an Experimental Design Tool on Students' Learning. *Optimizing STEM Education With Advanced ICTs and Simulations*, 58-83. https://doi.org/10.4018/978-1-5225-2528-8.ch003

Moore, E. B., Chamberlain, J. M., Parson, R., & Perkins, K. K. (2014). PhET Interactive Simulations: Transformative Tools for Teaching Chemistry. *Journal of Chemical Education*, *91*(8), 1191-1197. https://doi.org/10.1021/ed4005084

Ashcroft, J. M., Cakmak, A. O., Bautista, E., Wolf, V., Blatti, J., Davis, D., … Ehrmann, R. K. (2018). It's RAINing: Remotely Accessible Instruments in Nanotechnology to Promote Student Success. *Current Issues in Emerging eLearning*, *4*(1), 63-99.

Rodriguez, B., Wolf, V., Bautista, E., Timberlake, S., Shiffley, J., Smith, J., … Ashcroft, J. (2018). Bridging the Gap Between "Rocks for Jocks" and the Mars Sample Return Program: Using NASA Resources and Remote Access to Promote Geology. *Science Scope*, *41*(8), 48-57. https://doi.org/10.2505/4/ss18_041_08_48

Ashcroft, J. M., Min, A., Bojanini, I., Hacopian, M., Schroeder, K., Cakmak, A. O., & Rodriguez, B. (2018). Cultivating Mars: A Problem-Based Learning Lab Designing an Oxygen-Rich Environment on the Red Planet. *Journal of Laboratory Chemical Education*, *6*(1), 4-11.

Nguyen, D., Nooruddin, F., & Backa, N. (2012). Determining Empirical Formula of Magnessium Oxide and the Chemical Formula of a Hydrate. *Marked by Teachers*. http://www.markedbyteachers.com/as-and-a-level/science/determining-the-empirical-formula-of-magnesium-oxide-and-the-chemical-formula-of-a-hydrate.html. 2012

Rodriguez, B., Jaramillo, V., Wolf, V., Bautista, E., Portillo, J., Brouke, A., … Ashcroft, J. M. (2018). Contextualizing Technology in the Classroom Via Remote Access: Using Space Exploration Themes and Scanning Electron Microscopy as Tools to Promote Engagement in Multidisciplinary Geology/Chemistry Experiments. *Journal of Technology and Science Education*, *8*(1), 86-95. https://doi.org/10.3926/jotse.341