

# Inclusive Science: Inspiring 8th Graders from Underrepresented Groups to Embrace STEM with Microbiology and Immunology<sup>†</sup>

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**Inclusivity in STEM requires practices that include transforming the culture in a classroom. This can be done not only by placing value on diversity but also by providing an engaging student experience, instilling a sense of belonging, and encouraging students at all levels to use a critical lens to solve problems. As a way to develop an inclusive science curriculum for students in a community that is among the poorest in New York state, local STEM organization Rise High Inc. partners with experts in STEM fields, K–12 educators, mentors, and community organizations to create sustainable low-cost, high-quality, engaging, and relevant content that sparks curiosity and exploration for this underserved community. The educators and mentors also have a unique opportunity to develop self-awareness about their own pathways and how they can use their experiences to enrich the classroom. An exemplary case is this highly interactive two-part instructional module in Microbiology and Immunology, which targets 8th graders and was designed in partnership with a local expert in these fields. This module offers creative means to learn and apply knowledge in realistic ways, while using easy-to-access materials in classrooms.**

## INTRODUCTION

In 1957, the launch of Sputnik by Soviet scientists sparked national interest in investing in STEM (1, 2). Additionally, this was also a catalyst for the expansion of US higher education and federal investment in scientific research (1, 2). Although STEM continues to be of national focus decades later, there are significant challenges when it comes to the disparities and underrepresentation in these fields. A 2018 report led by the National Science Foundation, highlights that the makeup of the science and engineering labor force is quite disparate, with 40% women and the following ethnic breakdown: 21% Asian, 6% Hispanic, 4.8% African American, 0.2% Native American, and 0.2% Pacific Islander (3). The underrepresentation of minorities and those from disadvantaged socioeconomic backgrounds in STEM has not gone unnoticed, and there has been an ongoing push to encourage inclusive

practices in STEM, starting in the classroom at the K–12 level (4). Over the past two decades, a major push has been geared toward improving teaching practices and curricula in STEM fields that are inclusive (5). Inclusivity is achieved by including students across differences and working to mitigate biases that lead to marginalization or exclusion (5). These inclusive practices allow for transforming the culture in a classroom by placing value on diversity, increasing student engagement, creating learning environments that position students as knowledge generators, valuing students' lived experiences as evidence, and encouraging students to use a critical lens to solve problems (6–8).

In the United States, STEM education faces a number of challenges, such as insufficient funding in K–12, lack of professional development for STEM teachers, and poor inclusive STEM education in K–8 (9). These challenges are also faced by higher education, with the additional problem of student retention within the first two years of matriculation, especially for underrepresented minorities (URM) (10). A recent report highlighted that black student retention in STEM is more complex, as students who withdraw from or fail a course are more likely to leave STEM careers, and, even more concerning, these students have a 67% chance of not earning a Bachelor's degree (10, 11). Studies investigating the attrition rates point to the structure of the first-year learning experience, such as the “weeding out culture” and

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the sense of not belonging, as a possible reason why students leave STEM (12–14). As a way to develop an inclusive science program where the curriculum focuses on the sense of belonging and a rigorous STEM exposure for students in a community that is among the poorest in New York State Capital Region, a local organization, Rise High Inc. (Rise High), partners with experts in various STEM fields, in academic and industrial sectors, as well as highly-qualified K–12 educators, mentors, and community organizations. The community that Rise High serves includes students in the City of Schenectady, where 21% of the population lives below the poverty line. This population represents 16% of all families, 38% of which are single-mother households. In these households 35% have children between the ages of 5 to 17 years. Its school district is highly diverse, and 79% of its student body is economically disadvantaged (16). The district experienced graduation rates of under 60% in 2017 and 2018, compared with an average of over 90% for New York State (11). Recently, the graduation rate has managed to pass the 60% mark (12). The goal of the Rise High program is to support a sustainable, engaging, and relevant STEM content that sparks curiosity and exploration for this underserved community (17). Here, we describe an example of a highly interactive two-part instructional module in Microbiology and Immunology targeting 8th graders, which was designed in partnership with a local expert who is an URM female scientist. The two-part module offered creative ways to learn about how Microbiology and Immunology are interrelated, with applications to realistic scenarios, while using easy-to-access materials in the classroom. This two-part module also builds on current pedagogical models of an inclusive classroom by creating a sense of belonging, promoted by engaged mentors and teachers, using inexpensive materials to carry out the experiments, and having a scientist who comes from the students' cultural background (5, 11, 13).

### Curriculum design and learning objectives

The objectives of the module were to create an experience where the students can 1) understand how a given problem that they will explore affects them personally, 2) apply the science learned to find solutions to challenges, and 3) realize that they, as an underrepresented group of students, can be that scientist and problem-solver. These experiences address relevance, problem-solving/critical thinking, and identity, respectively. The two, two-hour sessions were designed and delivered a week apart, per the weekly format of the program. The premise throughout the module was around being 99% microbial and 1% human, the students were encouraged to think of themselves as dynamic microbial ecosystems. Week 1 focused on three parts: 1) a discussion as to whether all scientists look like Einstein, as we wanted students to realize that they too could be part of science (13, 18); 2) learning to identify various bacteria from different parts of the body by microscopy,

differences in microbial shape, symptoms, and possible treatment methods; and 3) emphasizing that the students were microbial ecosystems. The latter led to stressing the importance of hand washing, demonstrated by the results of experiments conducted by the students after testing themselves for further evaluation. Week 2 introduced serology and the importance of antibodies as tools to identify pathogenic microbes that the students learned about in week 1. The students were challenged to apply what they learned to diagnose and render prognosis to “ill mentors,” based on symptoms they communicated. Their diagnosis was confirmed by testing a mock serum from the mentors using the enzyme-linked immunosorbent assay (ELISA). At the conclusion of week 2, students examined their hand swab cultures that demonstrated differences in microbial load before and after hand-washing. This final exercise helped identify the 99% non-human part of themselves. Although there were no formal assessments or student evaluations, anecdotal examples indicated that the module's objectives were clear and inspirational.

### PROCEDURE

This was a two-part module in Microbiology and Immunology. Each part was designed around activities that lasted a period of two hours. The module was co-taught by the research scientist and high school science teacher who co-designed and co-developed the module. Figure 1 shows images of the students identifying microbes and identifying the illnesses that their mentors had by performing ELISAs. The general safety guidelines, instructor materials, student handouts, bacterial fact sheets, images of ELISA model, and details on how to make the mock ELISA are provided as appendices 1 to 6.

### MATERIALS

#### Microbiology Module (Week 1)

1. Bacterial pathogens slide kit (Carolina Biological Supply, Burlington, NC)
2. 40x light microscopes
3. 5% sheep blood agar plates without antibiotics
4. Swab sticks
5. Lab coats
6. Name tags
7. Work stations

#### Immunology Module (Week 2)

1. Polyester/Nylon lab coats (Ultra Source, Kansas City, MO)
2. Name tags

3. Nitrile gloves
4. Safety glasses
5. ELISA model made from petri dishes, pom-poms, and pipe cleaners. Labels are important
6. Patient serum represented by phenolphthalein, bromothymol blue, iodine, and biuret (Wards Science, Henrietta, NY)
7. Amber glass dropper bottles, 100 mm well plates (Amazon, Seattle, WA)
8. Work stations

## LABORATORY SAFETY

Laboratory safety BSL2 safety practices were used during our laboratory exercises. Students were required to wear lab coats, safety glasses, and gloves. Laboratory stations were disinfected before and after each session. The microscopy slides to demonstrate different bacterial pathogens were purchased from Carolina Biologicals (Burlington, NC) and have been fixed and sealed specifically for student use. Students were asked to wash their hands with soap and water after completing their plating exercise. Non-toxic chemicals were used in any of the experiments including the mock ELISA. Because phenolphthalein was used as a component of the ELISA, safety glasses were used. The blood agar plates that were used to grow organisms from swabbed hands were sealed with parafilm for student observation and a “no open handling” policy was used. The plate cultures were disposed of in a BSL2 receptacle and autoclaved. These guidelines are in accordance with ASM laboratory biosafety guidelines (<https://www.asm.org/Guideline/ASM-Guidelines-for-Biosafety-in-Teaching-Laborator>).

## TECHNICAL HIGHLIGHT

The use of ELISA kits to detect antibodies or infectious agents can be impracticable in under-resourced academic settings due to limited funding and resources. The premise behind ELISA kits, which involve a colorimetric change when antibodies bind to antigens, was simulated by substituting various indicator tests using phenolphthalein, bromothymol blue, iodine, and biuret. The indicator tests not only kept the integrity of the lesson while making it more accessible, but they are commonly found in schools, making this an accessible tool that allows students of all socioeconomic backgrounds to be able to learn the ELISA technique. We also made models of the ELISA kits using pom-poms and pipe cleaners. These models allowed our students to link the technique to the actual understanding of the mechanism itself as the students were pointing to the primary and secondary antibodies as well as the fluorophore components of the model while they were performing the ELISA.

## Week 1: The Microbiology Module. Exploring the microbial world

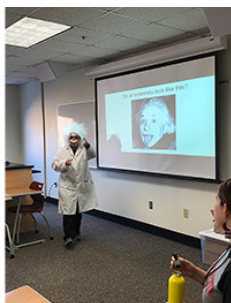
### Section 1. Do all scientists look like Einstein?

As the initial introduction, the students walked into the classroom and discovered that their invited lecturer looks like Albert Einstein, wearing a wig, mustache, and lab coat. The conversation began with a warm and excited welcome, followed by a series of questions: 1) Who am I? 2) What is a scientist? and 3) Do all scientists look like Einstein? The Einstein lecturer, using a series of images, demonstrated that scientists come from diverse backgrounds, and that in fact scientists look just like the students. This allowed a discussion about inclusivity in STEM and whether they had already met other experts in STEM who looked like them during their participation in the Rise High Program the year before. The students were able to identify several experts in science and engineering. The Einstein lecturer then made the big reveal by removing the costume, and formally made an introduction to reveal their identity. In our case, the Einstein scientist was a female from an underrepresented group, which facilitated an immediate connection for many of the students and created a sense of belonging for them. The microbiologist referred to all the students in the room as scientists and “doctors in her team,” which made the students immerse themselves in the important work that was about to take place in the classroom (Fig. 1).

### Section 2. Looking at the microbial world

Prior to the laboratory exercise, the microbiologist gave a 10- to 15-minute presentation that helped the students understand the size of microbes, how humans are 99% microbial and 1% human as they are dynamic microbial ecosystems, how their microbiota influences overall health, and lastly, a discussion about pathogenic microbes. The students were divided into five stations to learn about the microbes that cause disease. The stations were 1) bacteria that form spores, 2) bacteria that infect the gut, 3) bacteria that infect the lungs, 4) bacteria that cause throat infections and high fevers, and 5) bacteria that cause skin and venereal diseases. Each station had a 40x light microscope, slides that pertain to the theme of the station, bacterial fact sheets, and a data collection worksheet for the students to draw what they observed about the microbes at each station (Appendices 1 and 2). The students rotated through the stations every 12 minutes until they returned to their original stations. While the students were exploring the microbes, they were allowed to write questions on sticky notes. These notes were placed on the board and reviewed by the microbiologist during the regroup at the end of section 2 (Fig. 1).

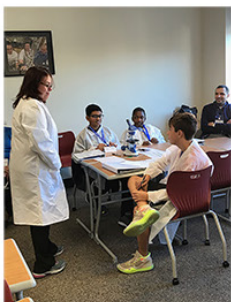
Week 1: Microbiology Module



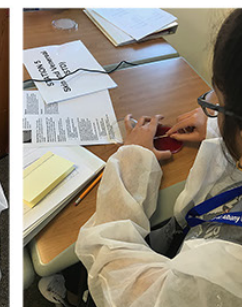
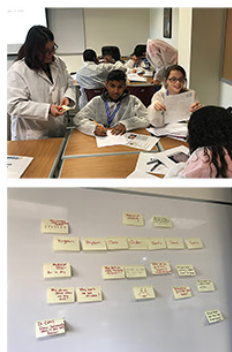
Do all scientists look like Einstein?



Exploring the microbial world

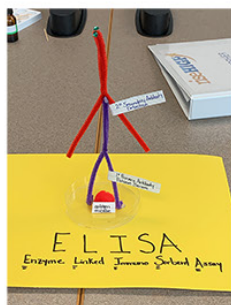


Encouraging students to use a critical lens to solve problems



Hand swabbing before and after hand washing

Week 2: Immunology Module



Students learn how an ELISA works



Students predict what illness their mentors have



Performing an ELISA



Students test serum from all of their four mentors



Mentor is given his diagnosis based on the ELISA results



The team is happy to know that their prediction was correct and confirmed by ELISA



Comparing hand swabs from week 1

Figure 1. Student activities during the two-week module in Microbiology and Immunology.

### Section 3. Exploring our 99% non-human part using swabbing technique

In this section, the students were challenged to explore their own microbial communities by learning how to properly collect swab samples of their hands and plate these samples on blood agar plates, before and after washing their hands. We found that leaving this activity for the end of week 1 built suspense and the desire to return the following week (Fig. 1). This activity also created a sense of inclusivity, as all the students were interested in learning about how they were all part of the microbial world and how their microbes would compare with one another. This general excitement for comparison led the microbiologist to put together a collage of the findings discussed in section 3.

## Week 2: The Immunology Module. Using immunology as a tool in the microbial world

### Section 1. What is serology and what is an ELISA?

In this section, the students were divided into four stations and the scientist challenged them to think about what happens when we spin blood inside a centrifuge. We found that the students were familiar with a centrifuge based on movies or news reports that they had seen, which allowed us to take advantage of the lived experiences of students, a connection that we used to acknowledge and interest them further, creating a climate of engagement from all the students in the classroom. The students looked at pictures of separated blood and learned that antibodies are present in the “clear liquid” called serum. When asked what an antibody was, the students mentioned words like protection, immune system, or something like an antidote. The students learned that there were different classes of antibodies in the serum. The lecture then explored the Enzyme Linked Immunosorbent Assay (ELISA). Using the ELISA props made from pom-poms and pipe cleaners, the students discovered that an ELISA requires that the plates be coated with the microbe or antigen, and that the primary antibody be that of their ill mentor. They also learned that the secondary antibody was a detection antibody, and it was animal-derived and raised against the human primary antibody (Appendix 3). Once this concept was repeated by all the groups, we performed an ELISA (Fig. 1).

### Section 2. Performing an ELISA and identifying the bacteria that are making the mentors ill

Prior to doing the ELISA, all four mentors came to the front of the room and read scenarios out loud, sharing their symptoms (Appendix 4). The students generated predictions about what pathogen was making their mentors ill, using their knowledge from week 1. These predictions were shared on the white board. Each station had the bacterial fact sheets from week 1, as well as mock serum from each of their ill mentors, labeled 1 to 4. Based on which vial tested positive, as indicated by a colorimetric change similar to what would be seen in an ELISA, the student had to inform

the ill mentor that they were positive (Appendix 5). To confirm their prediction, the students opened an envelope that contained the official test result. We found that every station was able to predict the microbe and perform the ELISA correctly. Furthermore, the students commented on how much they had learned about the individual microbes, feeling they could predict with certainty the ELISA results.

### Section 3. Revisiting our 99% non-human part using swabbing technique

In this section, we revisited the idea that we are 1% human and that microbes were all around us. The scientist presented swab samples from her cell phone, computer, kitchen sink, toilet, and dog. The students were also eager to see their agar plates from the previous week. The scientist put together a collage of all of plates prepared by the students, mentors, and teachers. Students learned about the *Staphylococcus* microbes and various fungi that live on their hands through an exploration of the growth on their blood agar plates. The students enjoyed looking at how many microbes were on their skin before washing their hands. They seemed to enjoy it more when their peers', mentors', or teachers' hand washing practices were not as good and showed an increase in microbial growth on the plates. The original plates were collected for proper disposal after observation by the students. Color pictures of individual plates were given to each student to take home and share with their families (Appendix 6).

### Emphasis on respect, appreciation, and inclusiveness

The Rise High program also emphasizes respect, appreciation, and inclusiveness. Students are taught to say thank you and appreciate the time that the scientist, teachers, and mentors have taken to share with them. They also learn to embrace diversity and that every question is important.

## CONCLUSION

Partnerships among experts in the sciences, community organizations, and the K–12 and college academic sectors is key in creating high-quality, engaging, and relevant content that sparks curiosity and exploration. The input from experienced local educators, especially in under-resourced settings, addresses unmet needs that make learning experiences effective and inclusive (5, 11). Meanwhile, the technology and industry experts bring a real-life application context, expertise, and passion that make the experience more real for the student. The experts also have the opportunity to share their stories and paths taken that led to their current careers. These shared experiences can serve as an inspiration for the students to follow an otherwise unknown path (11, 19). Recent studies have suggested that instead of continuing to approach STEM education as an often “leaky” pipeline, we should encourage an alterna-

tive pathway model (19). In the pathway model, there are multiple routes towards the required training for science careers (19). The second part of this model highlights that the underlying problem is not an undersupply of graduates in science but barriers that undervalue these alternative routes taken by women and minorities (19). Creating partnerships that encourage alternative pathways can help bridge gaps where we often lose future scientists, such as lack of mentorship, role models, and networks, while increasing these students' socioeconomic mobility and inclusion in the STEM community (13, 20).

## SUPPLEMENTAL MATERIALS

- Appendix 1: Microbial station cards
- Appendix 2: Observation worksheet
- Appendix 3: ELISA model
- Appendix 4: Scenarios for ill mentors
- Appendix 5: Reagents used to simulate an ELISA
- Appendix 6: Student and mentor plates before and after handwashing

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