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# Nuestra Ciencia: Transforming Microbiology for Spanish-Speaking Elementary and College Students

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**Synopsis** This forward-looking perspective describes the university–elementary bilingual partnership program Nuestra Ciencia. This program aims to simultaneously tackle two parallel sets of challenges, the first related to recruitment and retention of Latinx into science, technology, engineering and mathematics (STEM) fields, and the second related to generalized microbiology misconceptions. Latinxs are severely underrepresented in STEM fields, in part because they face systemic barriers and typically arrive at college with a weaker science foundation from their K-12 education and thus are less likely to be drawn to STEM majors. Beyond grappling with the science content, Latinx students reach college with assumptions about who belongs in science practices and professions, which in turn negatively affect their representation in STEM careers. Misconceptions also plague microbiology education, and most students reach college with deep-seated yet inaccurate ideas about the microbial world, such as the ways in which vaccines and antibiotics work. Unfortunately, lack of microbiology literacy has a direct impact on personal choices that can affect individuals but also the success of public health and environmental policies. Nuestra Ciencia addresses both sets of problems, as we work with interdisciplinary groups of undergraduates to develop engaging experiments for elementary classrooms that illustrate microbiology concepts, and then visit bilingual classrooms to lead the experiments in Spanish. Lessons have accompanying resources in Spanish and English for teachers and students, including background information, handouts, and assessment tools. In this article, we outline the background, goals and components of the program, review activities developed for elementary students, and share potential impact and lessons learned. Additionally, we explore future directions and outreach activities, especially in relation to online learning.

## Perspectives on microbiology and Latinxs in STEM

Most students reach college with only a vernacular knowledge of microbiology, and this can interfere with their understanding of microbiology concepts (Briggs et al. 2017), besides having a direct impact on personal choices that affect individual well-being and public health. Additionally, students reach college with misconceptions about science and science, technology, engineering and mathematics (STEM) careers which limit their engagement. Students typically internalize that only white men can be scientists and that science should be conducted in English. In particular, Spanish-speaking Latinx students face discrimination and significant achievement gaps even though current understanding of the way language and science competency develop suggests that children draw on their first-language proficiency as an asset for STEM learning. In the following section, we describe our perspective on the sets of challenges that we encounter in these two very distinct fields (microbiology education and Latinx representation in STEM) and how the implementation of our program Nuestra Ciencia, which connects college and elementary students, aims to tackle those challenges (see Fig. 1 for a graphic summary).

## Preconceptions about and marginalization of Latinxs in STEM

Latinxs are the youngest and fastest-growing demographic, accounting for 18% of the US population (Census Bureau 2018), and a quarter of all K-12 students and more than half of students in states such as New Mexico and California (Gándara 2015). However, Latinxs occupy only 6% of STEM professions. Latinx men make up 4% of the STEM workforce, while Latina women account for only 2% (National Science Foundation 2017). Although great strides have been made, with a 74% increase in STEM credentials earned by Latinx students between 2010 and 2013, these graduates are more likely than their White counterparts to gain employment in lower paying professions, becoming assemblers or technicians rather than engineers or physical scientists (Santiago et al. 2012).

The research on the recruitment and persistence of Latinx students in undergraduate STEM majors is robust (Cole and Espinoza 2008; Taningco et al. 2008; Baker and Robnett 2012). Studies show that the number of math, science, and English classes high school students take is directly related to their choice of major and that standardized test scores, AP classes, and GPA correlate with persisting in STEM majors (Taningco et al. 2008; Crisp and Nora 2012). Therefore, lacking access to high-quality coursework throughout K-12 greatly disadvantages Latinx students. Students tend to come with a weaker foundation in STEM, missing prerequisites but also lacking confidence in their abilities. Not surprisingly, students tend to show less interest in STEM careers when they receive worse grades in these content classes and more interest when they are satisfied with their science and math classes (Crisp and Nora 2012). Another factor is the college type, as Latinx students are more likely to attend community colleges where they do not have access to the same research opportunities, making them less likely to choose STEM majors (Crisp and Nora 2012; Ovink and Kalogrides 2015). Needing to earn money to stay in school or support the family can be a deterrent for pursuing often time-intensive STEM degrees and longer term commitments of medical or graduate school, especially for Latina women (Crisp and Nora 2012). On the other hand, the family often plays a powerful role in supporting Latinx students to pursue STEM careers. In fact, "parental encouragement has been shown to be one of the strongest influences on Hispanic students' early educational aspirations" (Crisp and Nora 2012). Additionally, Latinx students can envision a career in STEM more easily if their parents are employed in STEM fields.

Not having an equal representation in STEM fields is a current economic and social justice issue but also affects those K-12 students looking for similar role models and mentors when considering different career paths in the future. Researchers have documented the importance of a personal connection or role models in science (Sorge et al. 2000; Beeton et al. 2012) and recognition by others as a science person (Carlone and Johnson 2007). Role models have been shown to encourage Latinx students to enter science professions and persevere as well as feel a sense of belonging. Seeing someone that looks like them doing science can help to change their views of scientists, and help them envision their future in STEM. Role models can also help counter negativity and stereotypes from others in the future. Role models can support the younger students' current and future science identities, encouraging them during the activities while showing them new possibilities in science careers.

While role models are invaluable, it is important to note that the underrepresentation of Latinx people in STEM is complex. Much of the research in schools focuses on deficit models (i.e., Taningco et al. 2008) rather than illuminating systemic issues and using an asset-based approach (Rodriguez and Morrobel 2004; Darder and Torres 2014). However, a handful of scholars have delineated barriers including access to high-quality academic preparation and resources (Villenas and Deyhle 1999; Crisp and Nora 2012). Latinx students in K-12 are more likely to have instructors with less experience with science material or teaching overall. They are often taught low-level "boring" content, without inquiry experiences or labs (Villenas and Deyhle 1999; Peterson-Beeton 2007; Flores and Smith 2013; Alfaro and Umaña-Taylor et al. 2015). To exacerbate the problem, Latinx students face discrimination from teachers and peers, and low expectations from others (Villenas and Deyhle 1999; Johnson 2011; Cantú 2012; Flores and Smith 2013). Whether outright discrimination, implicit bias against Spanish, low-quality instruction, or lack of role models, the factors from elementary through college are additive. By the time Latinx students start college, they tend to have lower self-confidence, not see the relevance of science to everyday life, and view science as a career for others. Even if interested in science, they tend to

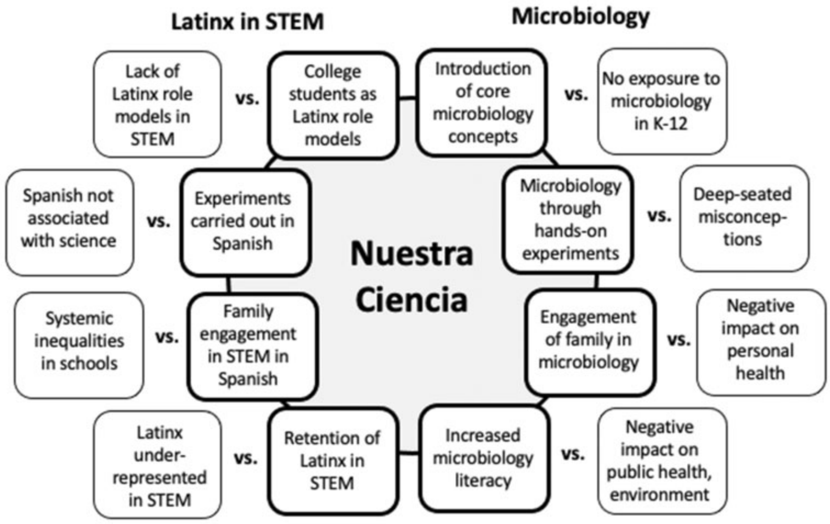


**Fig. 1.** Summary of the parallel sets of challenges and negative consequences in the fields of Latinx retention in STEM and microbiology and the ways in which Nuestra Ciencia addresses them.

lack awareness of science careers and have trouble seeing themselves as a scientist due to stereotypes (Sorge et al. 2000), including implicit and explicit bias against Spanish in science classrooms.

### Role of Spanish in learning science

Spanish is an important factor considering that 73% of Latinxs speak Spanish at home (Krogstad et al. 2015), and children draw on their first-language proficiency as an asset for STEM learning (Stevenson 2015). As one simple measure of the benefits of bilingualism in science classrooms, researchers identified the top "critical terms" listed by science educators in English and found three-quarters of these words are frequently used Spanish cognates (Bravo et al. 2007). The recognition and intentional implementation of these cognates promoted effective instruction in both languages, increasing the likelihood of concept and term recognition (Bravo et al. 2007). A few studies have documented more nuanced benefits for students communicating in both English and Spanish when learning the "so-called language of science" (Poza 2015, p. 1), and leveraging their home language and cultural funds of knowledge (Garcia-Sanchez and Orellana 2019).

A great deal of recent research focuses on incorporating underrepresented students' ways of thinking and doing, including their home languages, into learning at school (Ladson-Billings 1995; Upadhyay 2006; Basu and Calabrese Barton 2007; Barton and Tan 2009; Gay 2010; Aronson and Laughter 2016; Brown 2017; Garcia-Sanchez and Orellana 2019). However, this practice of "culturally responsive teaching" (Gay 2010) is less common in science classrooms than in other subjects (Aronson and Laughter 2016). Some science teachers still dismiss culturally responsive teaching because they are "teaching science, not culture" and feel that "science is science" regardless of the language or context of instruction (Harris and de Bruin 2018). Even in bilingual classrooms, the most common model is transitional or subtractive, where Spanish is phased out over time as students develop competency in English (Palmer 2011). Aligned with this goal, most of the researches on the use of Spanish in science classrooms focus on helping students achieve proficiency in English as a precursor to science competence. Spanish can be viewed as a supportive "crutch," or step along the way of reaching mastery in science, which is ultimately conducted in English (Palmer 2011).

While English is the de facto language of the United States, and it is important for students to develop proficiency, this focus in science classes can make students view Spanish as a second-class language, and not the language of science. As one undergraduate facilitator observed (Table 1), it is hard to separate language proficiency from subject proficiency, and students that are not fully fluent in English may see themselves as "bad at science." Even in classes where students are encouraged to use Spanish and often translanguage or code switch between English and Spanish, students internalize the "implicit institutionalized bias against Spanish" (Stevenson 2015) and prefer to communicate in English (Babino and Stewart 2017). This could be because Spanish is seen as less academic, as shown

**Table 1** Reflections on valuing Spanish in science classroom

| |
|---|
| "I felt stupid when I was a kid. Even when I understood the question and knew the answer, I never raised my hand because my English was not good enough. I don't think anyone could have known the difference between me not knowing something and me knowing it but not having the language skills to explain it." —undergraduate facilitator |
| "I wish I had something like this when I was a kid. I liked science but I never thought it was for people like me. No one in my family or even in my neighborhood had a college degree." —undergraduate facilitator |
| "That was so much fun. I didn't know that Spanish-speaking moms could be scientists." —elementary student participant |
| "You all go to Cal Poly? People speak Spanish at Cal Poly? How did you get to go?" (referring to the undergraduate facilitators) —elementary student participant |

from a study of 10-to 12-year-old native Spanish speakers. In this study, 72% of the language in the laboratories, when conducting work with peers, was in Spanish; however, in the classroom setting, only 27% of the words used were in Spanish. In the classroom setting, students were more often presenting their answers to the teacher and using English as a way of showing proficiency. Students revealed in interviews that they preferred speaking English with the bilingual teacher because the teacher valued English (Stevenson 2015).

Researchers can also reinforce the notion that English proficiency is necessary for being successful in science, such as Flores et al.'s conclusions that to improve in chemistry "the students realized they could perhaps work harder, and focus more on the development of their English language skills" (Flores and Smith 2013). Messages from researchers and society in general present this view that English is a necessary prerequisite to participating in science. The majority of prestigious, high-impact journals are in English, and many scientists choose to publish in English to advance their careers, while the impact of publications written in non-English languages is overlooked (Di Bitetti and Ferreras 2017; Ramírez-Castañeda 2020).

Although educators have successfully curated spaces for students to value both languages in science class (Infante and Licona 2018), teachers in bilingual programs can struggle with unintentionally preferencing English and send messages counter to their program's goals of obtaining dual proficiency (Palmer 2011). In science classes where Spanish-speakers are considered English language learners, teachers can focus on students mastering English and view Spanish in the classroom as a distractor rather than an asset to learning (Stevenson 2013, 2015). Even in classrooms with predominantly Spanish speaking students or bilingual instruction, most studies are focused on science instruction in English, and Spanish is incorporated through more informal peer communication or translation (Flores and Smith 2013; Stevenson 2015). Leveraging peers' language skills to help translate, while valuable, can also position Spanish as a second-class language. Peers have been shown to translate from Spanish, but can also belittle or laugh at Spanish-speaking peers for not understanding (Flores and Smith 2013; Stevenson 2013, 2015). Therefore, we advocate for conducting science in students' home languages, so they can feel comfortable expressing themselves and engaging in scientific practices, build up disciplinary knowledge, and see Spanish as an asset to their learning in science and participating in the scientific world (Table 2). Providing microbiology experiences in Spanish is a key component of Nuestra Ciencia, as a way of incorporating students' funds of knowledge and positioning Spanish as the language of science (Table 2).

Overall, Nuestra Ciencia counters the typical science experiences for Latinx students by providing engaging inquiry-focused microbiology activities in Spanish, with extension activities aimed to engage family members (Table 2). The elementary students are asked to interview family members about topics such as herbal remedies or best practices for making bread and yogurt (Table 3). In these extension activities with families, we hope that elementary students bring the microbiology concepts they learned in class to their loved ones, while simultaneously validating and elevating scientific practices at home (Table 2). Additionally, undergraduates benefit from designing the extension activities, as they reflect on their experiences in elementary school but also the scientific knowledge present in their families and communities. The relationship between elementary students and undergraduates is invaluable. The young learners can more clearly envision a future in STEM, while the undergraduates feel empowered and more connected to their communities (Table 2). The research indicates that being a role model for

**Table 2** Summary of Nuestra Ciencia program objectives for K-6 and college students

| K-6 students | College students |
|---|---|
| Learn core microbiology concepts | Reinforce core microbiology concepts |
| Learn through hands-on activities that leverage funds of knowledge | Develop activities and generate materials for students and teachers that leverage funds of knowledge |
| Exposed to science in home language | Gain experience in bilingual science instruction |
| Address preconceptions and make connections to everyday life | Address own microbiology preconceptions and make connections to everyday life |
| Get involved in scientific inquiry, apply scientific method | Get involved in research, practice science communication, gain writing and presentation skills |
| Exposed to Spanish-speaking role models | Empowered as STEM role model and community advocate |

**Table 3** Sample of activities developed for in-classroom experimentation

| Grade level | Outline of experiment | Core microbiology concepts addressed | Common preconceptions |
|---|---|---|---|
| K-2 | Compare abundance and diversity of microbes in unwashed hands versus hand sanitizer versus hand washing | Impact of microorganisms | Using hand sanitizer is better at removing microbes than washing hands with water and soap |
| K-2 | Yogurt production | Impact of microorganisms<br>Metabolic pathways | Live bacteria in food will make you sick |
| 3-4 | Assess antibacterial effect of spices | Impact of microorganisms<br>Metabolic pathways | Antimicrobials are all human-made synthetic chemicals |
| 3-4 | Bread production | Impact of microorganisms<br>Metabolic pathways | Microbes only have detrimental effects in foods |
| 5-6 | Herd immunity board game | Impact of microorganisms | Vaccines only protect vaccinated people, the decision to vaccinate or not only affects that individual |
| 5-6 | Variation in acid production from fermentation of various foods by mouth bacteria | Impact of microorganisms<br>Metabolic pathways<br>Microbial systems | The main goal of brushing/flossing is to remove bacteria from mouth |

younger siblings or community members can be impactful for undergraduate students of color (Johnson 2012; Jackson et al. 2016). Successful women of color studying STEM in college were motivated by using science to help others and advocate for causes related to race or gender (Johnson 2012). In Nuestra Ciencia, undergraduates gain opportunities to engage in authentic research and apply their biology knowledge outside of classes, mastering microbiology content through developing and teaching lessons for younger students. Through this process, undergraduates gain confidence as scientists, educators, and researchers (Table 2). As novice scientists, the undergraduates refigure their understanding of microbiology and help address misconceptions early on for the elementary students.

## Microbiology preconceptions

Unfortunately, regardless of grade level, students hold a pervasive set of misconceptions about microorganisms and their impact on the rest of the world. By the time they reach college, most students have only a rudimentary understanding of microbiology (Briggs et al. 2017). This is unsurprising, as microbiology is absent from the K-12 curriculum (National Research Council 2013) beyond the reinforcement of basic hygiene measures aimed at preventing disease transmission. Students are taught concepts such as evolution, ecosystem ecology, or cellular structure–function that are relevant to microbes, but applied in very different ways typically not covered in K-12 instruction. For example, the concepts of mutation and natural selection are consistently explained using organisms that reproduce sexually, whereas the majority of microorganisms reproduce by binary fission or assembly, and the main sources of genetic variation among individuals do not always include recombination. So, although those core evolutionary concepts apply to microbes, the process is shaped by very different forces and timescales. Despite the lack of coverage in K-12 education, many of these uniquely microbial activities have enormous consequences on individual and public health, as well as the environment. Daily life decisions such as whether or not to be vaccinated (Greenwood 2014; Garland et al. 2016; Micoli et al. 2021), request an antibiotic prescription (Faber et al., 2016; Korpela et al. 2017), eat or avoid certain foods (Cunningham et al. 2021), give birth by elective cesarean section (Hoang et al. 2021), breastfeed (Le Doare et al. 2018), use or avoid certain household products (Tun et al. 2018), and countless others, are best informed by a knowledge of how our actions alter microbial populations. Recently researchers have advocated for adding microbiology literacy as part of the "world citizen job description" (Timmis et al. 2019), because the effect of our actions on microbial communities, whether intended or not, has a profound impact not only on our personal lives but on the planetary function and health of the entire biosphere.

Precisely because microbiology is very much present in daily life, there is a large trove of vernacular with varying degrees of scientific accuracy. In a study aiming to identify sustained misconceptions in students who have taken college biology classes and are taking introductory microbiology courses, researchers presented students with a variety of true–false statements and found that many were correctly answered <50% of the time (Briggs et al. 2017). Additionally, the researchers found that even for questions with >50% correct answers, the explanation to the chosen answer was often incorrect. The most common misconceptions encountered can be mapped to the core microbiology concepts outlined by the American Society for Microbiology (ASM) Task Force on Curriculum Guidelines for Undergraduate Microbiology (Merkel et al. 2012). Both the misconceptions and the core concepts they relate to are summarized in Fig. 2 (adapted from Briggs et al. 2017). The most pervasive of those misconceptions detected in undergraduate students is that the appearance of antibiotic resistance in bacteria is related to previous exposure to the antibiotic, and this is connected to misunderstanding the core concepts of evolution, metabolic pathways, and information flow and genetics. As educators, this is a reminder that students will fit new knowledge into their existing frameworks, and they will often unwittingly modify the new information to fit a conceptually incorrect scaffold. Students bring many preconceptions to science classes, which are sensible based on their everyday experiences. However, everyday ways of reasoning can be limited or counter to scientific reasoning (National Research Council 2005). To change students' conceptions related to science, teachers need to explicitly address the ideas students bring with them (Windschitl et al. 2018). However, despite acknowledging the importance of directly addressing misconceptions when teaching, teachers struggle with incorporating them into lessons (Kambouri 2016), as addressing these preconceptions can be challenging for both the teacher and the student (National Research Council 2005). Science education researchers have outlined concrete ways to structure the learning process so teachers can leverage students' initial ideas and build out their understanding. For example, the Ambitious Science Teaching model illustrates how to intellectually engage diverse learners through eliciting students' ideas, supporting shifts in thinking over time, and helping students change their own thinking through revising evidence-based explanations. Teachers ask questions about what students already know, provide experiential activities, and facilitate discussions (Windschitl et al. 2018).

One way to address microbiology misconceptions before they become solidified is to expose students to microbiology core concepts before they reach college, so the framework they modify throughout all of K-12 is conceptually correct. Nuestra Ciencia was initially born out of a desire to fulfill a need for early microbiology instruction, by developing and testing elementary classroom-friendly experiments designed to connect daily life experiences to ASM core microbiology concepts (Fig. 1 and Table 2). Another goal was to introduce young students to the scientific method, including all the flaws and setbacks of experimental science. This prompted us to start an informal program at a local elementary school leading inquiry-based microbiology lessons. We chose to partner with a Spanish-immersion bilingual elementary school because the first author of this paper speaks Spanish and has children who attend the school. Since the school holds >50% instruction in Spanish for all subjects, we led our first microbiology experiment in Spanish in a first-grade classroom. Students were introduced to the classification of microbes as beneficial, harmless, and harmful, discussed requirements for microbial life, and predicted classroom environments that would support higher microbial abundance and diversity. Then students swabbed various surfaces, plated, and assessed microbial populations by incubation and colony counting. At the end of the 2-day experiment, a first-grade student approached the first author and said, "Esto fue muy divertido! No sabía que las mamás que hablan español podían ser científicas" ("That was

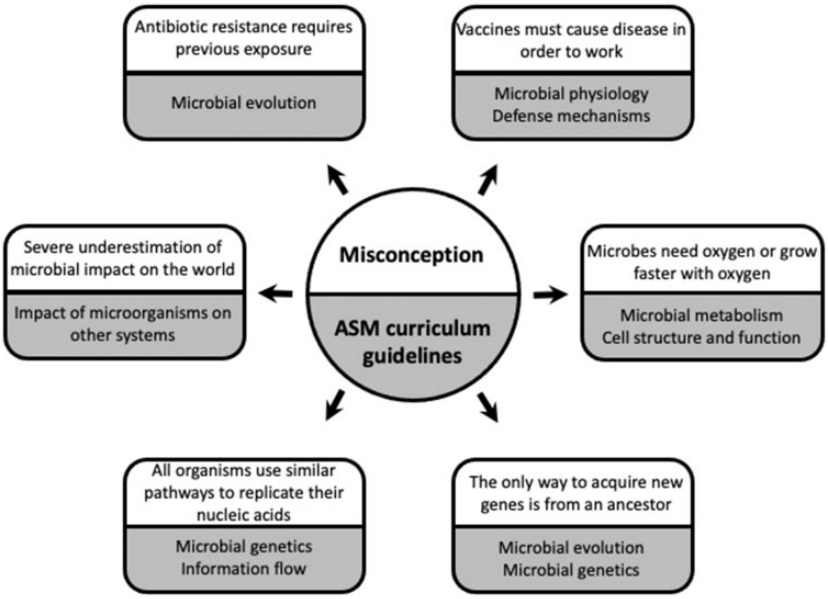


**Fig. 2.** Most common microbiology misconceptions found in college students taking introductory microbiology classes (Briggs et al. 2017) and the core microbiology concepts they relate to (Merkel et al. 2012).

so much fun. I didn't know that Spanish-speaking moms could be scientists," Table 1). This interaction exposed to us the second set of preconceptions that we summarized in the previous section and prompted us to expand the goals of our initial Nuestra Ciencia program (Fig. 1 and Table 2).

## Project description and goals

Grounded in two streams of literature, Nuestra Ciencia addresses two parallel sets of misconceptions: one about microbiology and another about Latinxs in STEM (Fig. 1). To address both, we recruited college students in science and education majors that spoke fluent Spanish to take microbiology beyond the college classroom and beyond the English language and into the bilingual elementary school classroom. The program objectives of Nuestra Ciencia are outlined in Table 2. The students in K-6 level receive early exposure to those core microbiology concepts, get involved in scientific inquiry in their first language, and connect microbiology to everyday life. The college students form teams that share their knowledge of biology and education plus bring developing expertise in diverse social and physical sciences (such as biomedical engineering and psychology). These interdisciplinary teams design and demonstrate age-appropriate experiments and accompanying teacher, student, and family outreach materials to demonstrate microbiology concepts, reinforcing those concepts themselves in the process. Additionally, the college students gain practice in science communication and experience with bilingual science instruction. As overarching benefits, the elementary school students are exposed to Spanish-speaking science role models and the college students are empowered as role models and community advocates.

The first author has run experiments informally since 2015 that combine all the main aspects of Nuestra Ciencia (hands-on experiments for elementary school children that reinforce core microbiology concepts, developed and led by college students in Spanish). Fueled by anecdotal data on the impact these experiments had on elementary students and their families, as well as college students, we decided to formalize and expand the program. As we intend for Nuestra Ciencia to be as broadly applicable as possible, our teams develop all materials in Spanish and English and generate detailed procedures for teachers that include background information and additional resources, accurate definitions for all the scientific terms introduced, lists of materials and links to purchase them online, and bilingual handouts and sample assessments for students so experiments are not limited to our program. Experiments cover a variety of ASM core concepts and introduce the scientific method and the processes that lead to the generation and vetting of new knowledge. The activities are designed to expose students to the concepts of sample variation, the need for controls and replicates, and train them in the process of drawing concrete conclusions that do not overextend beyond the actual experiment. In our experience, these are the parts of the scientific method that undergraduate researchers struggle to apply correctly and consistently, even when they are familiar with the theoretical basis. Examples of the experiments we have developed for different grade levels are summarized in Table 3.

For an example of our activities, at the K-2 level, we address the impact that microorganisms have in the environment and in our bodies and also the idea that using hand sanitizer is better than washing your hands, something that the majority of students believed. The activity starts with the undergraduate facilitators asking students whether it was good, neutral, or bad to have microbes in our body. They give a brief explanation about the difference between harmless microbes, beneficial microbes, and pathogens, and some basic hygiene concepts, like why people wash their hands or use hand sanitizer before eating. Students generate hypotheses and predictions about the relative abundance of microbes in unwashed, washed, and sanitized hands. All students touch the surface of half of a Petri dish with growth media. After that, half of the students wash their hands and the other half use hand sanitizer and then they touch the other half of the Petri dish. The facilitators incubate the plates overnight and the following day reviews the results and draw conclusions with the elementary students. From comparing the two sides of the Petri dish, students can conclude that both hand washing and hand sanitizer are similarly effective to remove most microbes from hands.

Another example, geared toward 5–6 level, encourages good dental hygiene. First, both elementary and college students complete a survey to assess their initial ideas. Students tend to think that brushing and flossing prevent cavities by removing bacteria from the mouth. The activity addresses this preconception and reveals how the first step in cavity formation is acid production from fermentation of carbohydrates by mouth bacteria, which in turns corrodes the enamel layer. Students learn that even though it is not possible to remove all bacteria from the mouth, it is possible to remove fermentable compounds by brushing and flossing after meals. To demonstrate this, the students crush a variety of foods and add them to tryptone broth with a pH indicator to show the production of acid by color change. The undergraduate facilitators add common mouth bacteria and let the tubes incubate. Students observe how foods rich in carbohydrates induce acid production by mouth bacteria, whereas foods low in carbohydrates, like egg whites, do not provide fermentable substrates and therefore do not stimulate acid production. As controls, the absence of added food leads to no changes in pH and adding pure table sugar induces a strong drop in pH. Other experiments in various stages of testing are outlined in Table 3, and more will be added as our working group develops them.

## Discussion

### Program implications

Our informal assessments suggest that Nuestra Ciencia activities had a positive impact at both the elementary and undergraduate level. Introducing these concepts early on and throughout each grade helps learners modify their framework and hopefully they will eventually enter high school and then college biology with scientifically accurate ideas. But beyond doing better in science classes, these ideas are important. Next-Generation Science Standards is about preparing students to think like scientists and become informed, empowered citizens. Part of this could be practicing healthy habits like handwashing but also, making informed decisions about healthcare and the environment. Also, the experiments that worked best were the ones that related to everyday experiences, as students appeared more likely to ask questions and also to talk at home about what they did at school. While the program now includes outreach and extensions to bring the family in, this was something we learned after the first session of teaching in the classroom. We have heard back anecdotal evidence that both the children and college students are discussing these activities with their families and providing information that would otherwise be inaccessible due to language barriers. Based on this feedback, we started developing experiments that purposely include an interview with family members, so that the family is involved in the acquisition of scientific knowledge.

We can already see the positive impact that developing and immediately testing the experiments and materials has on college students. In science, we rarely see an immediate practical impact of our research. The students participating in this project though, get to test the materials they developed in the field. They can feel they are making a difference, and this reconnects them to their major and rekindles their love for science. Additionally, working as part of Nuestra Ciencia revalues their first language and their experiences as Spanish speakers. Finally, Nuestra Ciencia is not only an outreach program but a research project as well, as we are collecting data for future publications. Participating undergraduate students take part in all aspects of research and acquire useful skills for their future careers.

Beyond addressing misconceptions about microbiology, there was evidence that the program broke down stereotypes about scientists too. We saw an immediate effect of the experiments being conducted in Spanish, as multiple students asked the college students where they were from, how come they spoke Spanish, and how they had gotten into college, whether they liked college, etc. (Table 1). When one of the undergraduate facilitators said her parents were from Mexico when introducing herself, lots of hands went up to share that their families were from Mexico too and they had an immediate connection to and saw themselves reflected in that student.

These connections between the elementary students, undergraduates, and families encourage multiple science pathways. The lens of branching, interconnected pathways helps avoid constraining participants to one "STEM pipeline," where people are either "in" or "out" of the pipeline. Instead, we encouraged trajectories, or diverse patterns of movement through branching pipelines (Guerra et al. 2012). We align with Dorph et al., who argue that "there is no single pathway to science" and that "science dispositions, practices, and knowledge are developed in diverse contexts that span many learner years and involve many formats" (Dorph et al. 2017). The traditional pathway in which elementary students must attend and graduate from college to become scientists (Fig. 3A), can be reframed as a nonlinear pathway in which becoming a scientist can pre-date attending college and where interactions with others involved in scientific inquiry at different levels can benefit people during all stages (Fig. 3B). Additionally, performing and being recognized as a scientist can establish an identity as a science person whether at the elementary or undergraduate level (Carlone and Johnson 2007). The program sets up a reciprocal relationship where undergraduates validate the elementary students' capabilities in science, while the elementary learners recognize the undergraduates as scientists (McLean et al. 2019).

Going forward, we plan to document how and when ideas are shifting about both science and scientists at the elementary and college level. We intend to conduct pre- and post-assessments and interviews to understand better what students know coming in about microbiology, what did they learn, what their attitudes are about science or scientists and how their ideas change. On the college student side, we will document through surveys and interviews how the undergraduate facilitators view their participation and how their identities as scientists evolve as they design and implement these activities.

## Future directions

In building curricula for bilingual elementary students, we discovered many potential directions in which Nuestra Ciencia can move forward. As local schools closed in March 2020, our in-classroom experiment format could not be implemented and we started exploring ways to attain the same objectives virtually. Initially, we saw this as a limitation, but we soon realized that moving our project online presented an opportunity to reach elementary learners and their families on a larger scale.

To make the information as relevant as possible, we decided to develop lessons and associated outreach videos around the current coronavirus pandemic and the related microbiology concepts. The topic of vaccines' mechanism of action was brought about by the undergraduate students currently involved in the project, as vaccine hesitancy regarding SARS-CoV-2 immunizations is a concern among Latinx communities (Khubchandani et al. 2021), who have been disproportionately impacted by COVID-19 (Tirupathi et al. 2020; Andrasfay and Goldman 2021). By doing this, we can inform the population on current and relevant matters like vaccination, antibodies, viruses, etc. with the goal of inspiring science-centered conversations among Latinx families. We are currently in the process of making our first videos explaining how vaccines work and how herd immunity protects a population.

As we brainstormed how to communicate scientifically accurate microbiology concepts, we discussed how "today's science communication is not our parents' experience of science communication" (Merson et al. 2018). We decided to make informative videos for young students, to show virtually in their classrooms as well as engage them at home. The idea that we could use social media to teach lessons to people opened the doors to multiple ways in which we could teach microbiology. The platform we started with is Tik Tok, a social media app released in 2016 and currently used around the world to create and upload short videos. With millions of users, it is a promising application that is accessed widely beyond English-speaking communities and is growing every day. Tik Tok enables us to reach Spanish-speaking people of all ages through engaging and entertaining videos. In our Tik Tok profile, we link to our Nuestra Ciencia website (under development) with additional, more detailed information in Spanish and English. We expect that K-6 students that see our videos in the classroom will then show them to their families, which might prompt them to visit our website continuing accurate scientific

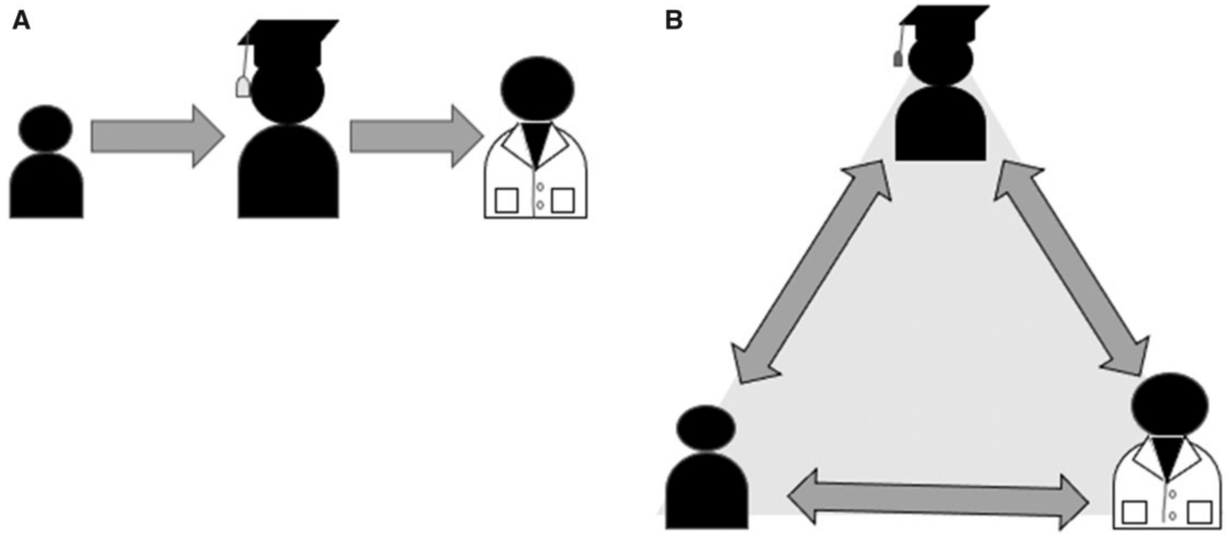


**Fig. 3.** Pathways to STEM. (A) Traditional pipeline model. (B) Interconnected pathways model.

information in Spanish and English. That way, 1-min Tik Tok videos can serve as eye-catching "hooks" to lead users to more in-depth information. Using social media platforms, we can redefine what it means to teach and learn microbiology. By creating resources in Spanish, we emphasize the strengths of elementary and undergraduate students who come from Spanish-speaking households and we break down the barrier between academic and home life. Nuestra Ciencia goals include elevating Spanish in the academic setting and also helping students discuss science with their families without having to translate from English.

Considering the multiple directions this project can take, we are excited about its potential. We will make accurate microbiology content accessible for students at multiple levels and ages, which could positively impact individual and public health outcomes. Undergraduate students working on this project will reinforce their own microbiology knowledge, gain research and interdisciplinary teamwork experience, and directly apply their own funds of knowledge associated with growing up in a Spanish-speaking household. They will also be role models for those who aspire to become future scientists, engineers, researchers, and community advocates and will promote diversity in STEM and spark interest in scientific inquiry in children at an early age. Additionally, the use of social media will allow us to reach learners within their households, bypassing the traditional institutional and language constraints for acquiring scientific knowledge. We hope Nuestra Ciencia will also inspire the implementation of similar programs, as many potential benefits of partnering undergraduate and elementary students through scientific inquiry are not limited to microbiology nor bilingual education.

## Data availability statement

No new data were generated or analyzed in support of this research. Please contact the corresponding author if you would like any additional resources on the information presented in this manuscript.

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## References

Alfaro EC, Umaña-Taylor AJ. 2015. The longitudinal relation between academic support and Latinx adolescents' academic motivation. Hisp J Behav Sci 37:319–41.

Andrasfay T, Goldman N. 2021. Reductions in 2020 US life expectancy due to COVID-19 and the disproportionate impact on the Black and Latino populations. Proc Natl Acad Sci U S A 118:e2014746118.

Aronson B, Laughter J. 2016. The Theory and Practice of Culturally Relevant Education. Rev Educ Res 86:163–206.

Babino A, Stewart MA. 2017. "I like English better": Latinx dual language students' investment in Spanish, English, and bilingualism. J Lat Educ 16:18–29.

Baker CN, Robnett B. 2012. Race, social support and college student retention: a case study. J Coll Stud Dev 53:325–35.

Barton AC, Tan E. 2009. Funds of knowledge and discourses and hybrid space. J Res Sci Teach 46:50–73.
Basu SJ, Calabrese Barton A. 2007. Developing a sustained interest in science among urban minority youth. J Res Sci Teach 44:466–89.
Beeton R, Canales GG, Jones L. 2012. A case study: Science identity formation of Mexican American females in high school chemistry. Chicana/Latina Studies 11:38–81.
Bravo MA, Hiebert EH, Pearson PD. 2007. Tapping the linguistic resources of Spanish/English bilinguals: the role of cognates in science. In: Wagner RK, Muse A, Tannenbaum K, editors. Vocabulary development and its implications for reading comprehension. New York, NY: Guilford. p. 140–56.
Briggs AG, Hughes LE, Brennan RE, Buchner J, Horak REA, Amburn DSK, McDonald AH, Primm TP, Smith AC, Stevens AM, et al. 2017. Concept inventory development reveals common student misconceptions about microbiology. J Microbiol Biol Educ 18:18.3.55.
Brown JC. 2017. A metasynthesis of the complementarity of culturally responsive and inquiry-based science education in K-12 settings: implications for advancing equitable science teaching and learning. J Res Sci Teach 54: 1143–73.
Cantú N. 2012. Getting there cuando no hay camino (when there is no path): paths to discovery testimonios by Chicanas in STEM. Equity Excell Educ 45:472–87.
Carlone HB, Johnson A. 2007. Understanding the science experiences of successful women of color: science identity as an analytic lens. J Res Sci Teach 44:1187–218.
Census Bureau. (2018, September 12). Hispanic heritage month (Report CB18-FF.07). [accessed 2021 June 14]. https://www.census.gov/newsroom/facts-for-features/2018/hispanic-heritage-month.html.
Cole D, Espinoza A. 2008. Examining the academic success of Latino students in Science Technology Engineering and Mathematics (STEM) majors. J Coll Stu Dev 49:285–300.
Crisp G, Nora A. 2012. An overview of hispanics in science, mathematics, engineering and technology (STEM): K-16 representation, preparation and participation. https://www.hacu.net/images/hacu/OPAI/H3ERC/2012_papers/Crisp%20nora%20-%20hispanics%20in%20stem%20-%20updated%202012.pdf.
Cunningham M, Azcarate-Peril MA, Barnard A, Benoit V, Grimaldi R, Guyonnet D, Holscher HD, Hunter K, Manurung S, Obis D, Petrova MI, et al. 2021. Shaping the future of probiotics and prebiotics. Trends Microbiol 4:S0966-842X(21)00005-6.
Darder, ATorres, R. 2014. The study of Latino education. Texas Educ Rev 2:62–74.
Di Bitetti MS, Ferreras JA. 2017. Publish (in English) or perish: the effect on citation rate of using languages other than English in scientific publications. Ambio 46:121–7.
Dorph R, Schunn CD, Crowley K. 2017. Crumpled molecules and edible plastic: Science learning activation in out-of-school time. Afterschool Matters 25:18–28 (https://eric.ed.gov/?id=EJ1138057)
Faber F, Tran L, Byndloss MX, Lopez CA, Velazquez EM, Kerrinnes T, Nuccio SP, Wangdi T, Fiehn O, Tsolis RM, et al. 2016. Host-mediated sugar oxidation promotes post-antibiotic pathogen expansion. Nature 534:697–9.
Flores A, Smith KC. 2013. Spanish-speaking English language learners' experiences in high school chemistry education. J Chem Educ 90:152–8.
Gándara P. (2015). Fulfilling America's Future Latinas in the US. Alexandria, VA: The White House Initiative on Educational Excellence for Hispanics.
Garcia-Sanchez I, Orellana MF. 2019. Language and cultural practices in communities and schools. New York, NY: Routledge Press.
Garland SM, Kjaer SK, Muñoz N, Block SL, Brown DR, DiNubile MJ, Lindsay BR, Kuter BJ, Perez G, Dominiak-Felden G, et al. 2016. Impact and effectiveness of the quadrivalent human papillomavirus caccine: a systematic review of 10 years of real-world experience. Clin Infect Dis 63:519–27.
Gay G. 2010. Culturally responsive teaching principles, practices, and effects. Handb Urban Educ 1:353–72.
Greenwood B. 2014. The contribution of vaccination to global health: past, present and future. Phil Trans Royal Soc London B Biol Sci 369:20130433.
Guerra JB, Calabrese BA, Tan E, Kang H, Brecklin C. 2012. Kay's coat of many colors: out-of-school figured worlds and urban girls' engagement with science. Identity Construction and Science Education Research. Brill Sense 43–60.
Harris A, de Bruin LR. 2018. Secondary school creativity, teacher practice and STEAM education: an international study. J Educ Change 19:153–79.
Hoang DM, Levy EI, Vandenplas Y. 2021. The impact of Caesarean section on the infant gut microbiome. Acta Paediatr 110:60–7.
Infante P, Licona PR. 2018. Translanguaging as pedagogy: developing learner scientific discursive practices in a bilingual middle school science classroom. Int J Biling Educ Biling 1–14.
Jackson MC, Galvez G, Landa I, Buonora P, Thoman DB. 2016. Science that matters: the importance of a cultural connection in underrepresented students' science pursuit. CBE Life Sci Educ 15:ar42.
Johnson CC. 2011. The road to culturally relevant science: Exploring how teachers navigate change in pedagogy. J Res Sci Teach 48:170–98.
Johnson DR. 2012. Campus racial climate perceptions and overall sense of belonging among racially diverse women in STEM majors. J Coll Stu Dev 53:336–46.
Kambouri M. 2016. Investigating early years teachers' understanding and response to children's preconceptions. EECERJ24:907–27.
Khubchandani J, Sharma S, Price JH, Wiblishauser MJ, Sharma M, Webb FJ. 2021. COVID-19 vaccination hesitancy in the United States: a rapid national assessment. J Comm Health 3:1–8.
Korpela K, Zijlmans MA, Kuitunen M, Kukkonen K, Savilahti E, Salonen A, de Weerth C, de Vos WM. 2017. Childhood BMI in relation to microbiota in infancy and lifetime antibiotic use. Microbiome 5:26.
Krogstad JM, Stepler R, Lopez MH. 2015. English proficiency on the rise among Latinxs Pew Research Center. https://www.pewresearch.org/hispanic/2015/05/12/english-proficiency-on-the-rise-among-Latinxs/.

Ladson-Billings G. 1995. Toward a theory of culturally relevant pedagogy. Amer Educ Res J 32:465–91.

Le Doare K, Holder B, Bassett A, Pannaraj PS. 2018. Mother's milk: a purposeful contribution to the development of the infant microbiota and immunity. Front Immunol 9:361.

McLean M, Nation J, Susko T, Harlow D, Bianchini J. 2019. University-elementary school partnerships: analyzing the impact of a service-learning freshman engineering course on students' engineering values and competence beliefs. Int J Eng Educ 35:1415–24.

Merkel S, the ASM Task Force on Curriculum Guidelines for Undergraduate Microbiology. 2012. The development of curricular guidelines for introductory microbiology that focus on understanding. J Microbiol Biol Educ 13:32–8.

Merson M, Allen LC, Hristov NI. 2018. Science in the public eye: leveraging partnerships—an introduction. Integr Compar Biol 58:52–7.

Micoli F, Bagnoli F, Rappuoli R, Serruto D. 2021. The role of vaccines in combatting antimicrobial resistance. Nat Rev Microbiol 19:287–302.

National Research Council. 2013. Next Generation Science Standards: for states, by states. Washington (DC): The National Academies Press. https://www.nap.edu/catalog/18290/next-generation-science-standards-for-states-by-states.

National Research Council. 2005. How students learn: history, mathematics, and science in the classroom. Washington (DC): National Academies Press.

National Science Foundation, National Center for Science and Engineering Statistics. 2017. Women, minorities, and persons with disabilities in science and engineering. Special Report NSF 13-304. Arlington, VA: National Science Foundation.

Ovink SM, Kalogrides D. 2015. No place like home? Familism and Latinx/a–White differences in college pathways. Soc Sci Res 52:219–35.

Palmer D. 2011. The discourse of transition: teachers' language ideologies within transitional bilingual education programs. Int Multiling Res J 5:103–22.

Peterson-Beeton R. 2007. Minority students' perspectives on chemistry in an alternative high school. Qual Rep 12:705–28.

Poza LE. 2018. The language of ciencia: translanguaging and learning in a bilingual science classroom. Int J Biling Educ Biling 21:1–19.

Ramírez-Castañeda V. 2020. Disadvantages in preparing and publishing scientific papers caused by the dominance of the English language in science: the case of Colombian researchers in biological sciences. PLoS ONE 15:e0238372.

Rodriguez MC, Morrobel D. 2004. A review of Latinx youth development research and a call for an asset orientation. Hisp J Behav Sci 26:107–27.

Santiago DA, Taylor M, Galdeano EC. 2012. Finding your workforce: Latinos in science, technology, engineering, and math (STEM). Washington (DC): Excelencia in Education. https://www.voced.edu.au/content/ngv%68706 (accessed 2021 June 14).

Sorge C, Newsom HE, Hagerty JJ. 2000. Fun is not wnough: attitudes of Hispanic middle school students toward science and scientists. Hisp J Behav Sci 22:332–45.

Stevenson AD. 2015. "Why in this bilingual classroom ... hablamos más Español?" Language choice by bilingual science students. J Lat Educ 14:25–39.

Stevenson AR. 2013. How fifth grade Latinx/a bilingual students use their linguistic resources in the classroom and laboratory during science instruction. Cult Stud Sci Educ 8:973–89.

Taningco MTV, Mathew AB, Pachon HP. 2008. STEM professions: opportunities and challenges for Latinos in science, technology, engineering, and mathematics. Los Angeles (CA): Tomas Rivera Policy Institute. https://eric.ed.gov/?id=ED502063 (accessed 2021June 14).

Timmis K, Cavicchioli R, Garcia JL, Nogales B, Chavarría M, Stein L, McGenity TJ, Webster N, Singh BK, Handelsman J, et al. 2019. The urgent need for microbiology literacy in society. Environ Microbiol 21:1513–28.

Tirupathi R, Muradova V, Shekhar R, Salim SA, Al-Tawfiq JA, Palabindala V. 2020. COVID-19 disparity among racial and ethnic minorities in the US: a cross sectional analysis. Travel Med Infect Dis 38:101904.

Tun MH, Tun HM, Mahoney JJ, Konya TB, Guttman DS, Becker AB, Mandhane PJ, Turvey SE, Subbarao P, Sears MR, et al. 2018. Postnatal exposure to household disinfectants, infant gut microbiota and subsequent risk of overweight in children. Can Med Assoc J 190:E1097–107.

Upadhyay B. 2006. Using students' lived experiences in an urban science classroom: an elementary school teacher's thinking. Sci Educ 90:94–110.

Villenas S, Deyhle D. 1999. Critical race theory and ethnographies challenging the stereotypes: Latinx families, schooling, resilience and resistance. Curr Inq 29:413–45.

Windschitl M, Thompson J, Braaten M. 2018. Ambitious science teaching. Cambridge (MA): Harvard Education Press.