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High School Students Explore Science Identity Through Participatory Science in Informal Education Program

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ABSTRACT

Science identity is central to students' desire to continue their STEM learning, yet many students struggle to see themselves as scientists. To create learning environments where all students can see themselves in science, we need a comprehensive understanding of the elements that contribute to student science identity. We developed and implemented a community-focused participatory science curriculum, examined how well Carlone and Johnson's (2007) three-part model of science identity—based on performance, competence, and recognition—captured students' experiences, and investigated novel elements of science identity that emerged from data voiced by the students who participated in our program. We employed mixed-methods analysis of pre- and post-program surveys, a repeated measures survey, and interviews from our ethnically and socioeconomically diverse high school student population. We suggest additional elements of science identity that emerged from our data and show how participation in our program impacted students' science identity. We found that students' definitions of a scientist can interfere with their ability to recognize role models or see themselves as scientists, highlighting the importance of countering stereotypes and emphasizing that performing scientific tasks is a key component to becoming a scientist. Our findings are relevant to educators seeking to encourage science identity development. We suggest that educators should support students to broaden their definitions of a scientist into definitions that could include themselves.

Keywords: citizen science, curriculum, environmental health, science identity

Introduction

Science identity is central to students' desire to continue their STEM learning. Science identity is defined as the aspect of the self that relates to science, i.e. the part that wants to be, and be perceived as, a "science person" (Carlone & Johnson, 2007; Gee, 2014; McDonald et al., 2019). Creating opportunities for science identity formation in all students can be an important way to foster a diverse future STEM workforce and a scientifically literate society. However, many students struggle to connect with STEM fields or to see themselves as scientists, especially marginalized students (Andersen et al., 2014). To create environments where all students can see themselves in science, we need a comprehensive understanding of student science identity and the factors that influence its development.

Carlone and Johnson (2007) posited that the prototypical science person would have a certain level of competence, be able to demonstrate it, and be acknowledged for it by others, resulting in a model of identity based on performance, competence, and recognition. In this study we examined Carlone and Johnson's (2007) science identity model through an out-of-school program that integrated science identity exploration with a student curriculum centered on empowering high school students as scientists. Bringing together concepts of place-based education, participatory science, and science identity in education, we conducted a mixed-methods study to address the following research questions:

- How well does Carlone and Johnson's (2007) model capture our students' experiences?
- In what ways does engagement in community-focused environmental participatory science interact with science identity among high school students?
- How do individual levels of performance, competence, and recognition relate to a student's sense of being a scientist?

Place-based Education and Exposure Science

Place-based education situates the learning experience in the place where learners live. The underlying premise is that students find greater meaning and thus learn more effectively when they closely examine and contribute to improving their own communities and ecosystems (Sobel, 2004). Smith and Sobel (2010) argued that by examining and understanding their own local environment, learners develop academic skills, a sense of relevance, connection to their environment, and strengthened ties to their community. In developing our program and curriculum, we applied place-based education with a focus on the fields of environmental health and exposure assessment. Exposure science, a subfield of environmental health, evaluates and quantifies the level of exposure to physical, chemical, or biological agents in the environment that can affect human health (Barr, 2006;

Lioy, 2010). Exposure science intersects well with place-based education given the emphasis on exposure to one's local environment, the potential health consequences of that exposure, and the ability to alter their exposure through behavioral or environmental modifications in response to monitoring results (Sobel, 2004, pg. 12). In our curriculum, we combined these concepts by giving students opportunities to explore their own exposures in their environments using sensor-based monitoring tools.

Participatory Science

Participatory science[1] describes the practice of people, often volunteers or nonprofessionals who may not have traditional scientific credentials, participating in scientific research. Modern participatory science programs in the United States were popularized by the Cornell Lab of Ornithology in 1995 with bird-watching programs where volunteers assisted scientists with research (Bonney et al., 2015). The 1990s and early 2000s saw significant growth in organized participatory science programs, along with increasing recognition of data collected by non-professional community scientists as valuable for scientific research (Kosmala et al., 2016; McKinley et al., 2017; Sullivan et al., 2014).

We use participatory science in our curriculum to introduce students to the idea that anyone who conducts scientific inquiries is doing science, and that doing science is not reserved only for people with academic or professional credentials. Our students engaged with ongoing national participatory science/citizen science projects, as well as collecting environmental health data in their own community. This approach, embedded within our place-based curriculum, ensured students engaged in genuine and authentic scientific research experience. STEM subjects are more engaging to students when they can connect what they are learning to real-world issues that are relevant to them and the places they care about (Honey et al., 2014; Smith & Sobel, 2010). Further, ample evidence shows how participatory science can play a significant role in effective and community-engaged science education, exposing participants not just to content knowledge from a specific citizen science project but also foundational connections to the nature and practice of science (Pandya & Dibner, 2018) By incorporating participatory science in our curriculum, we hoped to help students begin to see themselves in the role of scientist, and as members of the scientific community.

Science Identity

The development of a science identity involves a multifaceted process, and a series of science identity models have been proposed and tested. Based on their interviews with women of color in science academic programs or professions, Carlone and Johnson (2007) posited that the prototypical science person would have a certain level of competence, be able to demonstrate it, and be acknowledged for it by others, resulting in a model of identity based on *performance*, *competence*, and *recognition*. Performance refers to social performances of relevant scientific practices such as ways of talking and using tools. Competence refers to knowledge and understanding of science content, which may be less publicly visible than performance. Recognition refers to recognizing oneself and getting recognized by others as a science person (Carlone & Johnson, 2007; Hazari et al., 2010; Roberts & Hughes, 2022). Roberts and Hughes (2022) also demonstrated how an informal learning environment, like a strategically designed science summer camp, can provide increased external recognition, an important component of science identity, especially for marginalized or underrepresented students.

[1] Our curriculum materials produced during earlier years of our program used the term citizen science. We use the term participatory science in this paper following the recent shift towards more inclusive language (Citizen Science Association, 2023).

Carlone and Johnson's (2007) model also includes race, ethnicity, and gender identities as an important contextual factor influencing the construction of science identity.

Other researchers have built upon and modified Carlone & Johnson's (2007) model. Hazari et al. (2010) added a fourth component to science identity, *science interest*, which they define as the desire and curiosity to think about and understand science, which relates to external and internal motivation. Hazari et al. (2020) and others have also proposed that performance and competence can be combined into one construct, at least in some learning contexts, which is supported with quantitative and qualitative data from undergraduate students in physics, computer science, and engineering (Godwin et al., 2016; Große-bölting et al., 2023; Mahadeo et al., 2020). McDonald et al. (2019) simplified science identity into one component and used a single-item survey to measure self-recognition. Roberts & Hughes (2022) used Carlone & Johnson's (2007) model as their theoretical framework and focused only on recognition, separating internal and external recognition. Using empirical data, Estrada et al. (2011) proposed a different model for integration of underrepresented students in the scientific community composed of science identity, self-efficacy, and scientific values. Several of these studies have agreed that science identity is a key element for both intentions to pursue a career in science and also motivation to persist (Estrada et al. 2011). We approached the variations in the existing literature as different lenses that could be used to understand science identity, and the best lens to use may vary depending on the specific groups of students and their learning context. Considering these differing versions of science identity models, we sought to explore which most important elements apply in our context, an informal environmental science program with a diverse group of high school students.

Theoretical Framework

We used Carlone and Johnson's (2007) science identity model as a theoretical framework to guide our research, with awareness of the later modifications proposed by other researchers discussed above. This framework shaped our study instruments and our codebook as we conducted analysis, and we were attuned to look for ways in which data from our student population did, or did not, fit this model. Our study focused on testing the role of, and relationship among, student perceptions of performance, competence, and recognition as they relate to science identity in the context of our student program.

Materials and Methods

Program Design

We developed an engaging, community-focused, environmental science summer program for high school students with the aim to foster participant explorations of science identity and implemented the program along with high school teachers hired as co-instructors. We designed the program to give students the opportunity to participate in authentic science in a real-world context, interact and communicate with their community and professional scientists, act as and be seen by others as scientists, and begin to see themselves as potential members of the scientific community. The Southern Illinois University Edwardsville (SIUE) STEM Center implemented this curriculum in an out-of-school summer program to situate the activities more directly in the broader community setting, leveraging the flexibility, community engagement, and authenticity that these learning environments often provide (Bell et al., 2009; National Research Council, 2009).

In summer 2021 we held a summer program in-person at a local high school. A limited number of students (seven) were recruited to keep the class size small and allow for social distancing during the COVID-19 pandemic. We offered a similar program in the summer of 2022 based at the SIUE STEM Center on campus, and expanded our enrollment to 30 students. We partnered with an Upward

Bound Math and Science program that served students from low-income families and families in which neither parent holds a bachelor's degree. Both summer programs contained similar content but summer 2021 was more compressed with nine days of programming over two weeks while summer 2022 was 13 days of programming over three weeks.

Student Curriculum

We developed a modular out-of-school curriculum in environmental sciences where high school students designed, implemented, and communicated findings from technology-rich, participatory environmental science research projects. Because our objective for the curriculum was to position students as scientists, we intentionally sequenced activities that included each step of the scientific process. The curriculum included topics with a specific focus on environmental health including air pollution, noise pollution, soil pollution, and the natural and built environment, with connections throughout to participatory science projects like Purple Air, iNaturalist, and the Noise Project (*iNaturalist*, 2025; *Noise Project*, 2025.; *Real-Time Air Quality Monitoring by PurpleAir*, 2025.). Our team, along with a group of experienced high school teachers, hired as co-instructors, then guided students in research study design, data collection, analysis, and communication of findings. The students also had many opportunities to interact with scientists, including guest speakers, university partners, and authors. With instruction from scientists and educators, students developed scientific research questions and considered what kinds of questions they could answer with the available equipment and time. As we helped students develop research projects, we emphasized personal connections and using science to understand and help their own community and environment. Students worked in small teams to create research posters and presented them at a research symposium to community members, peers, and school administrators (Table 1).

Table 1
An Overview of the Student Curriculum from Summer 2022

Summer Program	Description
Day 1: Citizen science and the nature of science	Students tour campus and learn about campus life. They learn about citizen science, its role in the scientific community, and submit data to iNaturalist. Students write blog posts about everyday interactions with science.
Day 2: Environmental health and soil pollution	Students learn about types of pollution and health impacts on people. Students collect soil samples, test soil chemistry, and map impacts of soil lead pollution. A guest scientist visits from the biology department.
Day 3: Air and noise pollution	Students learn about air quality, citizen science mapping of air pollution with PurpleAir, and graph data from their region. They learn about sound waves, noise pollution, and the Noise Project. Students analyze local noise data alongside Google Earth data to identify patterns of noise pollution and collect their own data with decibel meters.
Day 4: Humans across the landscape and introduction to research projects	Students learn about mapping land cover and impacts of human-modified landscapes. They learn about all of the tools they can use to design their own study, such as soil probes, X-ray fluorescence analyzer, and drones. Guest scientists visit from a nearby university.

Day 5: Research project planning and intro to data collection	Students practice collecting data and testing hypotheses for a short practice study. Students begin planning their own research studies in groups.
Day 6: Research design and planning	Students learn about sampling from a population with M&Ms, and about observational studies vs. experiments. Students visit three environmental scientists' labs on campus. They finalize research plans.
Days 7 and 8: Data collection	Students collect data for their research project.
Day 9: Understanding variables and using tables	Students learn about explanatory and response variables. They use noise and soil data collected by previous students near a local steel mill to practice using Google Sheets. The students make their own data tables.
Day 10: Data visualization and analysis	Students learn about what type of graph is best for which type of data, with examples of environmental data collected and graphed by previous students. Students make graphs of data from their own research.
Day 11: Science communication	Students learn about effective science communication and use a template to start creating their own scientific poster to share their findings.
Day 12: Scientific posters	Students continue working on creating scientific posters or can work on blog post or lab report.
Day 13: Poster symposium	Students practice presenting their posters with peers and then present posters at symposium for invited guests (parents, university community, teachers).

Our approach to crafting the curriculum employed the backwards design framework (Wiggins & McTighe, 2005), where we identified our expected learning outcomes and designed activity plans that aligned with those outcomes. We also employed the backwards design method at the whole curriculum level with elements of science identity in mind. For example, we positioned the poster symposium as our culminating activity because we knew we wanted students to be able to perform and be recognized for knowing and doing science through presenting their scientific poster. The curriculum underwent iterative development cycles consistent with the principles of design research (Reeves et al., 2005). Although the implementation described here was an informal summer program setting, the curriculum is also aligned for use in formal classrooms with U.S. national Next Generation Science Standards (NGSS), in an effort to make the curriculum useful to other teachers and educators who may be required to meet these standards within a school context. The curriculum partially fulfilled ESS3.C: Human Impacts on Earth Systems, ESS3.D: Global Climate Change, HS-ESS3-3: Create a computational simulation to illustrate the relationships among the management of natural resources, the sustainability of human populations, and biodiversity; HS-ESS3-4: Evaluate or refine a technological solution that reduces impacts of human activities on natural systems, HS-ESS3-6: Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity, PS4.A: Wave Properties, and HS-PS4-1: Develop a model of waves to describe patterns in terms of amplitude and wavelength and that waves can cause objects to move. Additionally, the curriculum incorporated most of the NGSS cross-cutting concepts, and covered all of the NGSS science and engineering practices (NGSS Lead States, 2013). We also used Carlone and Johnson's three science identity components (competence, performance, and recognition) to guide the design of our curriculum to support student identity exploration. For example, we designed activities to give students ample opportunity to perform scientific skills and receive recognition for their expertise. The final version of the full curriculum and supplemental lesson materials are freely available to download at: https://stemcenter.siue.edu/resources/curriculum/

Environmental and Sociocultural Setting

The students we worked with live in communities situated in the Metro East region of Illinois, United States, in a predominately postindustrial area directly across the Mississippi River from the larger metropolitan area of St Louis, Missouri. This region has a rich history in music and Black culture and has long served as an important hub of manufacturing and transporting industrial products. Following the ebb of the railroad economy and postindustrial decline, portions of the Metro East experienced large decreases in population in the later part of the 1990s and were left with a legacy of environmental contamination and a distressed economy (Nunes & Theising, 2011). An authentic place-based context for environmental learning is particularly important for the students in our focus area, because these communities have faced a long history of environmental injustices, with disproportionate exposure to industrial pollution and environmental contamination (Abel, 2008; Colten & Samsel, 1988; Kaminski & Landsberger, 2000; Vermillion et al., 2005). The population we worked with also included some students from rural, agricultural communities, and some from exurbs favored by people who work in the larger urban center of St. Louis across the river. The history of the Metro East shapes the environmental context and sociocultural background of the students we worked with, as well as the content of the place-based curriculum we developed.

Student Demographics

We obtained parental consent and participant assent for all 37 students who attended the 2021 and 2022 summer programs, which gave us an ethnoracially diverse student sample (Table 2). Our sample of students is fairly representative of the student population in the area, with a slightly higher number of Black, Hispanic/Latinx, and multiracial students and a lower number of White students as compared to the district as a whole. The demographics of the nearest school district are 52% White, 14% Black, 27%; Hispanic, 6% multiracial, and the remainder belong to racial/ethnic groups not sampled in our study (Illinois Report Card, 2023). We believe our findings to be representative of, and generalizable to, other diverse student populations that are from low-income families and/or would be the first in their families to attend college.

Table 2

Student Demographics

"I am…"		"I am…"		"What grade are you starting?"	
Male	54%	Latinx or Hispanic	32%	9th	30%
Female	38%	White	32%	10th	10%
Nonbinary	3%	Multiple	14%	11th	27%
Not answered	5%	African American or Black	14%	12th	23%
		Not answered	8%	Not answered	7%

Note: From surveys of 37 total students in (7 in summer 2021, and 30 in summer 2022). Percentages are rounded to the nearest whole number.

Research Design

We employed a concurrent triangulation mixed methods approach using both quantitative responses to surveys and qualitative data derived from student interviews. We chose a mixed methods approach as the most appropriate given our sample size and research questions, with the qualitative data providing vital nuance and corroboration when quantitative data were inconclusive or difficult to interpret on their own (Creswell et al., 2003). We collected and analyzed each data type separately and integrated the data when developing our interpretations. During analysis, we considered how the theoretical model of science identity and the conceptual frameworks of participatory science and place-based learning intersected in the participants' experience and in the program activities. The survey data provided us with a means to measure the students' science identity as they participated in the program and their responses to the interview questions allowed us to explore what led students to feel the way they did about their science identity. Throughout our analysis, we focused on direct student perspectives and prioritized the qualitative data in order to develop a rich, contextualized understanding. This study protocol was approved by the Southern Illinois University of Edwardsville Institutional Review Board.

Instrument Development and Data Collection

Three researchers (GB, CC, and SL) developed the semi-structured interview protocol informed by Brinkmann & Kvale's (2015, p.131) concept of thematizing the interview study. The approximately 15-minute interview consisted of 12 questions that were based on Carlone and Johnson's (2007) science identity model, with an emphasis on how students perceive their ability to perform science-related tasks, their perceived ability to perform these tasks with competence, and how they view their own and others' recognition of their science-related skills (Supplementary Materials).

We interviewed the student participants during the first two days of the program, and again in the final two days of the program.

We used two different types of surveys in our quantitative data collection, a long pre- and post-program survey given at the beginning and end of the program, and a shorter repeated measures survey that was given six times throughout the program. The pre- and post-program survey had identical items, each containing 33 questions with a 5-point Likert scale (Strongly disagree, Disagree, Neither agree nor disagree, Agree, Strongly agree). The questions were divided into five blocks: Competence (seven questions), Performance (seven questions), Recognition (seven questions), Science Identity (five questions), and Future/Careers (seven questions). The first three blocks of the long pre- and post-program survey (Competence, Performance, and Recognition) were adapted from the 5-point Science Self Efficacy survey (Estrada et al., 2011). The Science Identity block of questions was adapted from the 5-point Scientific Identity survey (Estrada et al., 2011). The final block (Future/Careers) was adapted from the 5-point Career Interest Questionnaire (Tyler-Woods et al., 2010). For all sections of the long pre- and post-program survey, we adjusted the language to fit our high school student audience and to reflect our focus on environmental sciences. At the end of each survey, students answered demographic questions (Table 2). Surveys were only administered in 2022, and we collected 29 complete surveys of the 30 student participants. We administered pre-program surveys on the first two days and post surveys on the last two days of the 2022 summer program (Supplementary Materials).

In addition to the longer pre-program and post-program surveys described above, researchers administered a short, repeated measures, 8-item science identity survey twice a week during the 2022 summer program, for a total of six implementations. The short survey was intended to measure potential changes in science identity during the program that might not be captured on the longer pre- and post-program surveys. The first seven items were adapted from Trujillo & Tanner's (2014) science identity instrument, which uses a 5-point Likert scale. The final item was from McDonald and colleagues' (2019) validated instrument. For this item, respondents selected from a series of five Venn diagrams showing overlap between two circles labeled "Me" and "Science Person" ranging between no overlap (lowest value) to complete overlap (highest value) between the two circles (Supplementary Materials).

Qualitative Analysis

After interviews were recorded, we assigned pseudonyms and used an artificial intelligence transcription service to generate draft transcripts from the audio files (Otter.ai). Once generated, one researcher reviewed and corrected the transcript draft using the original audio file. We developed an *a priori* coding framework based on Carlone and Johnson's (2007) model, as well as an initial emergent coding of interviews collected during the 2021 program implementation. These researchers then applied the incipient coding frame to a representative sample of pre- and post-program interviews (i.e., four pre-program interviews and three post-program interviews) to refine the coding frame. While applying the incipient coding frame, the researchers remained open to divergence and subtleties in the data that they perceived as potential emergent codes (Saldana, 2021). After an initial application of the coding frame, the researchers met to review their perceived emergent codes, discuss the coding frame, and further examine excerpts that seemed relevant to the research questions but lacked alignment with any of the *a priori* codes. This process resulted in a codebook that included 14 primary and 29 secondary codes (Supplementary Materials).

Following the development of the codebook, six researchers applied the codebook to 68 interviews from 2021 and 2022 (of our 37 total students, 36 completed pre-program interviews and 32 completed post-program interviews), meeting weekly to review and discuss the application of the codebook. Two researchers independently coded each interview with a more experienced researcher providing a third analysis of seven interviews (10%) to ensure that all researchers applied the codebook with fidelity and consistency. During our initial coding, we coded the interviews for the presence of codes without indicating the direction of association of the particular quote with the code. One researcher (CB) did a second round of coding where they coded each previously identified quote according to whether the student's comment was positively or negatively related to the concept. For example, a clear positive comment about science identity was coded as strong positive science identity, while a clear negative statement about science identity was coded as weak science identity. We conducted a similar process for identity, recognition, and competence, separating the students' quotes into negative association, moderate or unclear, or strong positive association with the main code (supplemental Table S1). After we finalized the coding process, we then held weekly meetings over the course of five weeks to further condense the codes into themes that informed our science identity conceptual model.

Quantitative Analysis

For the long surveys, our analysis included responses from the 29 students who completed both pre-program and post-program surveys before and after the program. We calculated the mean score of student responses for each research question block (i.e., Performance, Competence, Recognition, Identity, and Career/Future) and compared pre-program and post-program survey scores using Wilcoxon's matched-pairs signed-ranks test.

For the short surveys, our analysis only includes the 18 students who completed all six repetitions of the short survey during the program. We conducted two separate analyses on the short survey, considering items 1-7 as a separate instrument from item 8. Data from the short surveys were analyzed using a Friedman's rank test as a non-parametric repeated measures analysis tool. Prior to analyzing the short survey results for trends in science identity, we examined empirical correlations among the questions using Spearman Rank Correlation Coefficient (ϱ). The nonparametric Friedman's test was performed on the short survey results to check whether student responses varied overall among the six sampling dates ($N = 18$ students). All quantitative data analyses were conducted in R version 4.1.2 (R Core Team, 2023).

Methodological Triangulation

To integrate the quantitative and qualitative data, two members of the research team (CB and AD) met frequently during the analysis phase. CB triangulated qualitative findings from student interviews with the quantitative trends found in those same students' surveys, for example examining if students who spoke enthusiastically about the impact of the program in interviews also showed changes in their survey response from pre- to post-. AD steered the quantitative analysis and interpretation based on the qualitative findings. During triangulation meetings, the researchers considered areas of agreement with qualitative and quantitative data and corroborated these areas in the context of the science identity theoretical model with attention to the participatory science and place-based framework. All researchers worked together to integrate the qualitative and quantitative datasets until they reached consensus on their interpretations of these data.

Results

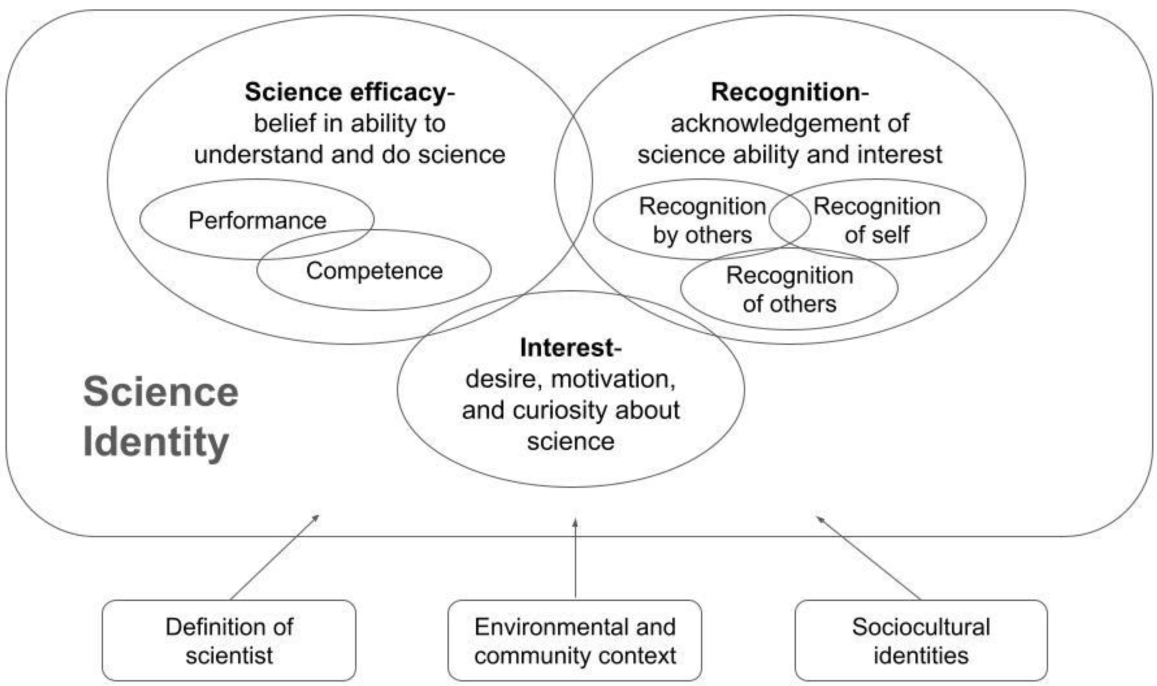
Qualitative Findings

Model of Science Identity for our Students

Through our analysis of the student interview data, we developed a model that modifies and adds to existing models of science identity (Figure 1). We started our research with Carlone and Johnson's (2007) model describing three dimensions of science identity: competence, performance, and recognition. Our model for science identity modifies and adds to those dimensions suggested by earlier scholars and has three main dimensions: *science efficacy*, *recognition*, and *interest*, all of which are influenced by contextual factors, the student's *definition of a scientist*, *environmental and community context*, and *sociocultural identities*. All of these elements are expected to change over time, and our data collection points represent snapshots of each student's relationship to these elements of science identity. Each of these dimensions is explained in more detail in the sections below, with examples of how our data supports the way we have constructed this model.

Figure 1

Our Model of Science Identity



Note: Our model includes elements of earlier models with several important additions based on our analysis of student data from our program.

Science Efficacy

In our proposed model, both competence and performance are grouped under the umbrella of science efficacy. Science efficacy in our model encompasses both scientific knowledge and understanding, as well as the skill to perform hands-on science tasks. We define science efficacy as the student's self-perceived ability to successfully know and enact science. We found it difficult to distinguish competence (knowledge and understanding of science content) from performance (social performances of relevant scientific practices) in our conversations with students. In fact, most of the over 150 interview excerpts coded for performance were double coded as competence. In contrast to Carlone and Johnson (2007), we did not collect GPA or assessment test scores to directly evaluate performance or competence, but rather asked students to describe their self-perceived scientific competence and performance in the interviews. When coding, we often could not disentangle student's perceptions of their competence and performance when they spoke to their belief in their science ability. For example, in his 2022 pre-program interview when we asked Ethan, "*What would you do to help in studying the environment?"* he replied, *"I could take more classes. You know, learn more about it so I can help contribute, to help fix anything that's going on. I think that's what I can do. Take more classes."* This interview question was intended to ask students about what they could do, as in actions they could take to conduct environmental research. However, we saw students had varying interpretations of what it meant to "study" the environment. Even when we discussed this quote as researchers, it was difficult for us to determine Ethan's meaning. It is possible he was conflating acquiring knowledge through classes (building competence), with performance of scientific studies because he did not consider performance and competence to be appreciably different components of his science efficacy. Or, he may have described taking classes as a way to build scientific competence because he interpreted the interviewer's question as pertaining to competence instead of performance, or science efficacy in general. However, it is possible Ethan meant that taking more classes (i.e., acquiring greater competence) was a necessary step that would precede taking action to study the environment (performance).

In addition to the quote above, many other students did not make a distinction between scientific knowledge and the skill to perform scientific tasks when responding to the interview questions, and/or interpreted questions intended to be about one of these aspects of efficacy as pertaining to either or both competence or performance. Students also often mentioned that they enjoyed learning science and doing science without making a strong distinction between the two, and that for them learning science has been their way of doing science. The difficulty of making the distinction between performance and competence in both crafting the interview questions and in interpreting student responses further justifies the way we present the relationship between competence and performance in our model. Moreover, because we designed the program to be student-led and hands-on, our approach had little division between content and practice, which may have contributed to the blurring of these two concepts in student responses to the interview questions. Given these findings, we grouped performance and competence under science efficacy in our model.

Science Interest

Our model incorporates *science interest*, which we defined as a desire and/or curiosity to think about and understand science, including external and internal motivation (Carlone & Johnson, 2007; Hazari et al., 2010). Based on our definition, a person can be interested in science without perceiving that they are good at science. Some students came into the program with a preexisting interest in science. This interest was often tied to their school experience, as seen when we asked Mia in her pre-program interview what makes her feel like a scientist or a science person:

> Mia: *Well, I've always liked science. And so like, whenever in school, or here in the summer program, we do summer science projects, I really liked that. I think science is something that I really love to do more than anything else. Really interesting and fun.*

Science interest varied among students – some expressed no interest in science, while others had a more nuanced view, like Alex when asked about being a science person in his pre-program interview:

> Alex: *Because I find some of the stuff interesting. Like physics and chemistry, that stuff is really cool. Being able to, like, mix two things together, and get something completely different…I find that pretty interesting…geology and that kind of stuff, I don't find that interesting.*

Alex's interest in specific STEM disciplines but not others lead him to express a more complex identification with the term science person, illustrating the role of interest in science identity. Further, we also saw evidence of students expressing science interest that they connected to future potential careers. When asked if she feels like a science person, Camila talked about her identity as a science person in relation to her interests, including an interest in the healthcare field:

> Camila: *Well, I think it's always been my favorite subject. I like learning about living things, or just things around us, like what we've just been learning. And then I like the healthcare field, and that has a lot to do with science."*

Camila's expression of a specific career interest suggests an intention to reengage, which is considered by Hidi and Renninger (2006) to be an important characteristic of the ultimate phase of well-developed individual interest. Although we did not measure future reengagement directly, we saw in our interviews that the intention to reengage and independently pursue an interest in science factored into how students talked about their science identity.

Recognition

Our model divides the recognition component into recognition of self, recognition by others, and recognition of others (Figure 1). Recognition of self and recognition by others are similar to Carlone and Johnson's (2007) differentiation between self-recognition and recognition from meaningful others. We did not differentiate between meaningful and non-meaningful others when approaching how a student perceives their identity. In Carlone and Johnson's (2007) model, the inclusion of recognition by others is especially important for people who are from marginalized groups. We also added a third type of recognition, which we named recognition of others, which refers to a student's recognition of the experts we exposed them to as scientists.

Overall, we found that many students had positive associations with the idea of being recognized as a science person. Students mentioned that others thinking of them as a science person would make them feel smart, curious and fun, or proud. In her pre-program interview, when asked how it would feel to be seen as a scientist, Camila put it this way:

> Camila: *I think that would make me feel just proud of myself. It shows what I have accomplished, and people can actually recognize me for things that I do.*
>
> INTERVIEWER: *Awesome. Okay. How does it make you feel to think that your family thinks you're a science person?*
>
> Camila: *Um, I think it's really cool, really interesting just because there's not really…a lot of my family…like, my parents are immigrants. A lot of my family comes from Mexico. So there's not really much…not a lot of education, I guess. So, I know that my parents, they didn't go to school for too long. So just knowing that I'm gonna go higher.*

Camila expresses that recognition by others as a science person is something that she considers important and seems to indicate that this recognition is something she wants to achieve and would be proud of. In our study, we found meaning in what we believe is an equally important factor to consider – a student's ability or inability to recognize scientific role models even when presented with them. The students were given the opportunity to interact with many scientists through the course of the program, including guest speakers and scientists who helped organize the program (some of whom are authors on this manuscript). However, students who interacted with scientists in the program had trouble identifying these professionals as scientists, especially if these people did not easily align with the student's notion of what a scientist looks like or does. One student illustrated her lingering lack of clarity by asking the researcher conducting her post interview "*Um, are you guys declared scientists*?" This question seems to imply not only that the student had not received our intended message that the researchers she was interacting with in the program were scientists, but also that there was some unnamed external authority that "declared" someone a scientist, rather than defining anyone who does science as a scientist. In another example, Camila did not immediately identify participating in archaeological field work with one of our researchers as working with a scientist:

> INTERVIEWER: *Have you ever met or worked with any scientists before?*
> Camila: *Um, I don't think so.*
> INTERVIEWER: *What did you do last week?*
> Camila: *Hmm?*
> INTERVIEWER: *What did you do last week?*
> Camila: *Oh! I did anthropology with you.*

In the above example the interviewer is a scientist with expertise in ecological archaeology as well as science education research and is a white woman. It is possible that these characteristics did not immediately call to mind the idea of a scientist for this student. For students who responded to the question about knowing or working with scientists with an affirmative answer, it was more common for them to reference a different scientist they met in the program, Dr. Ben. This other scientist, Dr. Ben, is a white, male, environmental scientist, with glasses, in his 50s. Despite all program staff making efforts to contradict these stereotypes, students seemed to have perceived Dr. Ben as more easily fitting into their ideas of what being a scientist, and doing science looks like. For example, Camila, the same student quoted above, who had apparently forgotten her interviewer was herself a scientist, later stated in her post interview "*I think it's really cool to work with actual, real scientists. And you can see their different perspectives and insights, and then Ben how he's like an actual college professor*." The two women (one white, one Latina) who conducted Camila's pre-program and post-program interviews respectively were also scientists, and both held faculty positions at the university. Our reading of the interviews indicated that this perception and recognition of other scientists as scientists, especially any limits or barriers to this recognition, can be an important factor in the development of students' own science identity.

Definition of Scientist

Connected to the question of who students recognize and identify as scientists, is our inclusion in the model of the students' definition of scientist. This new construct is a key part of the context in which students form their science identity, and the student's definition of a scientist or science person can influence the other elements that make up science identity. That definition, which may change over time, is based on students' ideas about who a scientist is, what they look like, and what they do. As previously discussed in describing students' recognition of others, a student's exposure to a professional scientist as a potential role model does not guarantee that the student will receive the message intended by educators. We found that many students carried a strong preexisting definition of a scientist that seemed to be influencing their conception of their science identity. During our interviews, we asked students about what a scientist looks like and what scientists do. Here is one example of a student's mental image of a scientist from her pre-program interview:

> INTERVIEWER: *So what about in like TVs and movies? What kinds of scientists do you usually see, like on television, and what are they doing?*
> Olivia: *I don't really… Well, people think of chemists and things like that. Like making things. You know like, with the...*
> INTERVIEWER: *Yeah, like, what do you picture when you picture a chemist?*
> Olivia: *Kind of like, I don't really know what they're called, like, the glass thing?*
> INTERVIEWER: *Oh, yeah. Like a glass beaker?*
> Olivia: *Yeah, beakers, yeah things like that. They're, like, mixing stuff and then maybe it will explode. You have to wear safety goggles and stuff like that.*

Like Olivia, other students also showed they were aware of the stereotypical scientist image, some bringing up lab coats and glasses or goggles. However, we also had several students in pre-program interviews who specifically articulated that they did not want to stereotype who a scientist could be. Some students said things like: "*Just depends on the field…it can be…anyone can be a scientist, whoever wants to be a scientist.*"

Students' experiences of the learning opportunities in our program seemed to be strongly mediated by who they considered a scientist to be, and whether this definition aligned with the activities they themselves were engaging in. As we explored students' perceptions of their science identity, we asked students both about being a "science person" and about being a "scientist." Most students, even those who expressed a strong sense of themselves as a "science person" made an important distinction between "science person" and "scientist." Rachel explained the difference this way in her post interview:

> INTERVIEWER: *Do you feel like a scientist?*
>
> Rachel: *I mean, scientist and science person are two different things if you think about it. Like, a scientist is somebody, they want to further their career in science, they want to be a scientist, work with other scientists, that sort of thing. Now, science person is more of somebody who is like, 'I wouldn't mind doing this', 'I wouldn't mind being a scientist'. It's like, they're considering being a scientist. And a scientist is more like the person who is an esteemed scientist, like they've made their choice. Science person is somebody who's venturing into that choice, but isn't fully there yet. So do I feel like a scientist? Maybe. Maybe I could, I could see myself being a scientist.*

Seven other students expressed that to be a scientist one would need a degree or advanced training, would need to be a professional, would need to be an adult, or would need to have money and resources. One student replied when asked in his post interview if he was a scientist, "*Last time I checked, I don't have thousands of dollars and a lab yet…*" Many students expressed the idea that they had the potential to become a scientist in the future but did not currently feel like a scientist, although they had conducted scientific research in our program. These sentiments again reveal the importance of the students' definitions of what it means to be a scientist in the development of students' science identity. Even when we explained to students the concept that in participatory science, people without a degree can be scientists in their own community and guided them to engage in conducting scientific research themselves, some students retained a more restricted definition of what it means to be a scientist.

In post interviews some students expressly stated that their view of scientists had changed through participating in our program: "*Before this program, I was saying, like, Albert Einstein, that's my scientists. Or even Dr. Frankenstein, just, like, movie scientists. But yeah, I think now it's just anyone.*" We posit that these evolving views of who a scientist is and what a scientist does are important in how a student understands themselves in relation to science. If a student has a mental image of a scientist that is dissimilar from themselves in appearance, or in the type of actions they are doing, it will be harder for the student to see themselves included in their definition of a scientist, even when they have actively engaged in scientific inquiry. This definition of a scientist can potentially inform all the other aspects of science identity. For example, if a student does not consider their interest in veterinary medicine to be an interest that aligns with being a scientist based on their current definition of scientist, this would limit the impact of their interest in veterinary medicine on forming their science identity.

Environmental and Community Context

One key component of our model, the *environmental and community context*, reflects our place-based learning approach and the students' sense of responsibility and agency in environmental stewardship and the connections within their community. Our program content placed a strong emphasis on establishing connections between scientific research and students' everyday lives. We found that this curricular content was particularly effective in creating personally powerful experiences for students.

Many of our students made connections between the people in their communities and their non-human environment. During the interviews, we defined community as *the people and places where you live, like your neighborhood, school, street you live on*. During pre-program interviews, we directly asked students what they would like to learn about the places where they live and if they could think of ways they could study the environment to help their community. Students struggled with conceptualizing their community during pre-program interviews and often made general statements, for example about the effects of global change or how more people should care about the environment. After the program, students still emphasized environmental issues, but following the program students also made direct connections between the broader environment and their personal experiences, including experiences of performing science. When asked what she liked about the program during her post interview, Valentina responded:

> Valentina: *I like, you know, my friends. And then doing a research project, I thought that was pretty fun because we got to do our own research by ourselves. I liked testing out the different equipment, and the soil testing, and the air monitor, that was pretty interesting...*
>
> INTERVIEWER: *Can you think of some ways you could study the environment to help people in places where you live? Thinking about your house, your school, parks, wherever you go?*
>
> Valentina: *I think we could put like, because with the air quality thing, I think we could put air quality testers in more places. So that it can be a resource to everyone. Like so that when you, let's say you walk into a restaurant, you can see what the air quality is. Just in case like, you know you have a health problem or something, you can see it and know that maybe you shouldn't stay there that long. And then you can find ways to improve it in that area. So, you can maybe find what's making the air quality bad.*

During post interviews, some students made direct connections between their communities and their specific research projects. For example, Justin mentioned that his neighbors would be interested in learning more about recycling and would be shocked to learn about how much recyclable material ends up in common landfills and would want to do something to help. This was a direct connection between his group's research project and his community. Students also talked about using knowledge and skills they gained at the program in their day-to-day lives, such as Valentina's quote above, mentioning the idea of placing air quality monitors in restaurants. When asked about what she liked about the program, Leah emphasized student agency and choice:

> Leah: *I liked that we got to do different things. [...] And then we got to pick our own project, instead of you guys assigning one to us. So it's like I could do something I actually liked, instead of always being told I had to do it like in school.*

As we can see from these quotes, students' science identity was influenced by the program's content. Students were able to make more direct connections with their environment and their community by applying their knowledge of environmental sciences and by connecting their projects' topics and results to real-life situations. At the end of the program, students were also more aware of how to use science in their local community, which is a direct reflection of our emphasis on participatory science, and place-based learning which served as the foundation of the curriculum we developed and implemented.

Sociocultural Identities

Our partnership with the Upward Bound program ensured we reached a student population with high sociocultural diversity due to their recruitment of low-income and potential first-generation college-bound students (Table 2). We found that the influence of sociocultural identity inevitably surfaced as we discussed aspects of science identity with students. For example, in Camila's quote above, she speaks about a desire for recognition of her science identity by others, and that desire is connected to the fact that her parents are immigrants from Mexico who did not have much access to education. Her feelings about how recognition plays in to her identity as a science person are clearly intertwined with her other identities. Although it was also not a part of our original research questions, we also saw that the sociocultural identities of the researchers, instructors, and visiting scientists also seemed to matter in how students experienced our program, such as the previously noted pattern of students like Camila more readily recognizing people as scientific role models if their sociocultural identities conformed to those stereotypically represented in science.

Associations Within the Model

Our analysis of the student interviews also yielded some intriguing associations among several elements within the model. We found a positive association between a strong science identity and recognition by others. In fact, all 17 students who expressed a strong sense of themselves as a science person in their interviews also expressed moderate to high levels of recognition by others (Table S1). Many of these students came into the program with a strong sense of their own science identity, shown here by Mia in her pre-program interview:

INTERVIEWER: *So do you think that other people think of you as a science person, like your friends and family?*

Mia: *I think my friends do because I do have some friends, like my closer friends in my science class. And they always tell me, 'Oh, ya know, how did you understand that? Like, what did you put together to know that information?' And my family? I think they do, because I'm always talking to them, 'Oh, I did this in science class, I really liked it.' You know, I really want to do something in STEM. I think science is my favorite subject. You know, I really like to do science.*

INTERVIEWER: *Yeah. So you talk to them about it. Do you help your friends out in science class?*

Mia: *Yes…all the time. [both laugh]*

INTERVIEWER: *I'm sure they love that. So you like being seen that way–you like that people think of you as a science person?*

Mia: *Yes.*

In contrast, students who lacked a strong science identity also reported that others did not think of them as science people, as described by Noah in his pre-program interview:

INTERVIEWER: *Okay, so, do you feel like you're a science person?*

Noah: *Not necessarily.*

INTERVIEWER: *Okay, so you think you have an interest?*

Noah: *Not in science, I appreciate it. But I'm not interested in a career in science.*

INTERVIEWER: *Okay, okay. So how would you describe your feelings about science?*

Noah: *It is interesting. I do, I do appreciate it. I do like learning about it. It's just not something I want to spend the rest of my life working with and doing.*

INTERVIEWER: *Okay. So do you think like your family members or like your friends see you as a science person?*

Noah: *Uhh, no I wouldn't say so.*

These two quotes illustrate a stark contrast in these students' experiences of how their science identity is perceived (or not) by others. While we cannot confirm that this association between external recognition and strong science identity is a causal relationship, our interpretation of our qualitative data suggests that recognition by others may contribute to development of a strong science identity.

Quantitative Findings

Survey Reliability

We found good internal reliability on all five blocks of our long survey. Reliability of the performance was α=0.89, competence was α=0.93, recognition was α=0.96, science identity was α=0.91, and future plans was α=0.87. We also found good internal reliability on all 6 blocks of the short survey (Cronbach's Alpha ranging from 0.84 to 0.93).

Long Survey

We conducted a Wilcoxon matched-pairs signed-ranks test on the five survey blocks (Performance, Competence, Recognition, Identity, and Career/Future) for the 29 students who completed both pre- and post-program surveys. Our quantitative results showed that the only component that was significantly different between pre- and post-program surveys was competence ($p = 0.016$). All other components were not different between pre- and post-program surveys ($p > 0.05$). However, see below for further discussion of science efficacy in our triangulation of qualitative and quantitative findings.

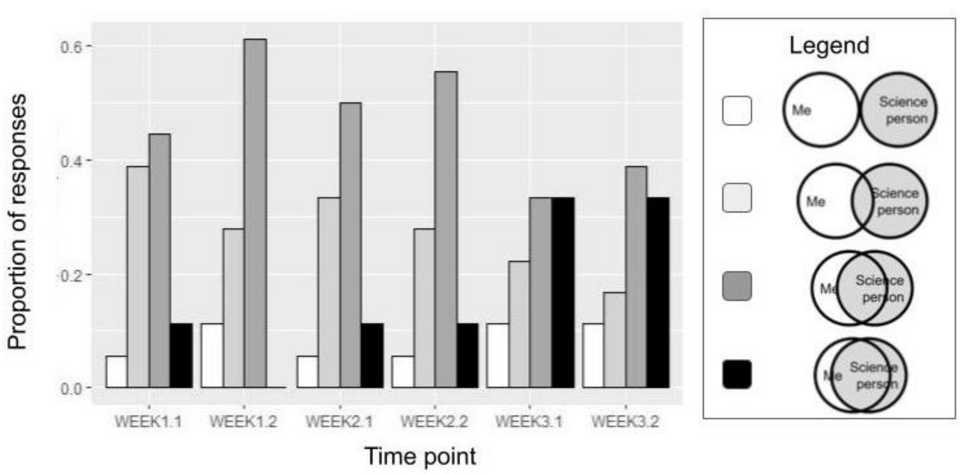
Short Survey

We used the short survey to get finer details on how students responded over time to each section of the three-week summer program. Likert responses to the short survey questions were all positively correlated with each other. The correlation between Question 5 ("I am a scientist") and the other questions was low to moderate, ranging from $\varrho = 0.28$ to $\varrho = 0.52$ (median $\varrho = 0.39$). Correlations between the remaining questions were higher, ranging from 0.31 to 0.83 (median $\varrho = 0.53$).

For the average of all eight questions, there was no significant change in student responses over the repeated measures (Friedman's $Q = 7.72$, $df = 5$, $p = 0.17$). A few participants of the total group ($N = 26$) exhibited a directional shift in their scores towards more extreme scores. In particular, for the average scores of Questions 1 to 7, Jeremiah's and Valentina's answers increased from 3.1 to 4.6 and from 4.0 to 4.9 between the first and last surveys. A trend was seen for Question 8 alone ($Q = 10.7$, $p = 0.06$), with a small effect size (Kendall's $W = 0.11$). Results for Question 8 are depicted in Figure 2. For Question 8, the number of students who selected the 4th option (out of 5 possible) for the Venn diagram overlap between "me" and "science person" increased from only a couple of students initially, to eight students in the last two surveys (Figure 2). This change shows an increase in identity as a science person during the last week of program participation for some of the students.

Figure 2

Trends In Student Survey Responses Over Time In Our Program.



Note: Students were asked to "mark the picture that best describes the overlap of the image you have of yourself and the image you have of a science person". A fifth option with fully overlapped circles was also offered but not selected by any students.

Triangulation of Analysis and Findings

Throughout our analysis, our decisions and interpretations were informed by emerging results from both the qualitative and quantitative data. We sought to corroborate our conclusions with both our qualitative and quantitative data as much as possible, especially through considering individual students' interviews and survey results together to form a more complete picture of their individual experience. We also made use of methodological triangulation when we saw that the quantitative results indicated a weaker correlation between question five and the other survey questions. Question five asked students if they agreed with the statement "I am a scientist." The first seven questions were adopted from the same instrument and expected to be significantly correlated, however, even students who responded more positively to the statement "I am a science person" did not always agree as strongly with the statement that they were "a scientist". This quantitative result coincided with our emerging qualitative discovery that students made a definite distinction between being "a science person" and "a scientist" during their interviews. These parallel emerging results in turn strengthened our conviction that some of the survey questions should be analyzed separately in our statistical analysis. Taken together, these quantitative and qualitative findings support our claim that students' definition of scientist impacted their interpretation of the term scientist in both the surveys and interviews, and that this evolving definition is a key element in understanding student science identity.

Science Efficacy

Our qualitative and quantitative analysis revealed tension in how competence and performance should be framed within student identity, whether as two distinct components or related aspects of a more encompassing latent concept like science efficacy. While our quantitative data showed a significant increase in competence following our program, performance did not show a statistically significant increase when analyzed as a separate quantitative variable. Because our qualitative analysis suggested that students perceived competence and performance as intertwined, we also calculated a combined score from these sections of the survey to create a new quantitative variable *science efficacy*. We calculated a new Cronbach's alpha value for science efficacy from the 14 pre- and post-program survey questions which related to this combined variable ($\alpha = 0.90$). A Wilcoxon matched-pairs signed-ranks test comparing pre- and post-program survey scores of the new science efficacy variable showed a significant change following our program ($p = 0.013$). On average, participants increased in their science efficacy following the program by 0.27 points on the 5-point Likert scale. This suggests that a combined science efficacy variable could be a meaningful measure if student perspectives suggest they perceive performance and competence as inexorably related. Our final model shows performance and competence as two related concepts grouped within the category of science efficacy to accurately represent the nuance of both our qualitative and quantitative findings.

Shifts in Science Identity

Through considering quantitative and qualitative results together for individual students, we saw further evidence that exposure to the program supported students' exploration of their science identity. Five students expressed notable increases in describing their science identities in post interviews compared to pre-program interviews (Table 3), and some students showed a quantitative shift in their responses to the science identity questions on the short survey. For example, when Jack started out in the program, he expressed uncertainty and an overall weak connection to science identity, "*Um…I mean, I don't see myself going to college for anything science related. But I don't particularly dislike science. I just like, I feel like most of the time when I'm in school, and they're teaching science, it's just always, you know, it's sooo… I guess they kind of killed it for me a little bit.*" However, following the program, Jack's responses to the Venn diagram science identity question on the short survey (question 8) increased by two full steps out of the five choices given, and similarly he showed a stronger sense of himself as a science person and scientist in his post interview responses:

> INTERVIEWER: *Okay, do you feel like a science person?*
> Jack: *Um…yeah.*
> INTERVIEWER: *Yeah? Can you tell me why?*
> Jack: *Well, I know a decent amount of science, about science. And we ran some tests. And, like, we collected data, observations. So I think I'm a science person.*
> INTERVIEWER: *Nice. Yeah. That's all science for sure. Do you feel like you're a scientist?*
> Jack: *Yeah.*
> INTERVIEWER: *Yeah? Cool. Can you talk a little bit about why you feel like a scientist?*
> Jack: *Well, because I've done some things that scientists probably do. Like I've collected data, and you know, have a hypothesis.*
> INTERVIEWER: *Yeah. Cool.*
> Jack: *Made observations.*

Jack is actually one of only a few students who expressed identification with the term "scientist." Jack expressed that the student-led research experience made him feel like a scientist, which is a noticeable increase in his sense of science identity compared to his perspective before participating in the program just a few weeks earlier. He pointed to specific hands-on activities like collecting data that felt authentic to him, and to important concepts of scientific research like having a hypothesis. Valentina was another student whose science identity scores increased on the short survey over the course of the program. Valentina also described the student-directed group research projects as memorable: "*I thought that was pretty fun. Because we got to do our own research by ourselves.*" These personal experiences they described in interviews about conducting scientific activities, such as research question development, data collection, and data analysis, coincide with these two students' quantitative increase in their science identity responses on the short survey.

Table 3

Strength of Science Identity Self-described by Students in Pre- and Post-Program Interviews

Responses to the question: *"Do you feel like a science person?"*	Students in pre-program interview (n=36)	Students in post-program interview (n=32)
Negative	13.9%	12.5%
Mixed	41.7%	31.2%
Strong Positive	41.7%	56.2%

Discussion

Based on our findings, we created a model of science identity that builds on previous research and adds modifications that arose from the data provided by the students in our program. Our model has three main dimensions (*recognition, science efficacy, and science interest)* that are informed by the *environmental and community context*, the student's *sociocultural identities*, and their *definition of a scientist*. Our model builds upon Carlone and Johnson's (2007) three components, but we nested performance and competence within *science efficacy*. Considering competence either as a sole construct, or as a combined element of science efficacy that incorporates competence and performance, our qualitative and quantitative analysis showed that science identity strengthened for some students during the course of our program. Previous research has highlighted how engaging in authentic scientific tasks can be important to science identity formation for high school students (Chapman & Feldman, 2017). Like others, we found support for the benefits of participation in student-led research (e.g., Jacquez et al., 2013), and additionally, exposure to citizen science or participatory science may broaden students' mental images of a scientist to one that could include themselves.

Similar to Hazari et al. (2020) we found that students expressed convoluted feelings around performance and competence. While our quantitative survey data showed some differences in the patterns for competence and performance measures from surveys, our qualitative data suggested that these two elements could not be reliably identified as separate concepts in the way students discussed them in interviews. Other researchers have also supported that performance and competence be considered as a combined construct in studies with undergraduate students in physics (Godwin et al., 2016) and computer science (Mahadeo et al., 2020; Große-bölting et al., 2023). Our study reveals further insights into students' perceptions of what it means to be confident and/or effective in science, suggesting that students may not always make a strong distinction between disciplinary knowledge versus performing scientific skills, and/or that this distinction may be difficult to differentiate, at least in some learning contexts. This finding coincides with Hazari et al.'s (2020) finding that when students feel able to perform, they also feel more competent, and when they feel competent, they also feel able to perform. The blurring of competence and performance could also be related to our study population being younger high school students who were less experienced in science than the undergraduate science students in the Carlone and Johnson (2007), and we also depended solely on self-perceived measurements of performance and competence rather than collecting any learning assessment data as previous researchers working in formal learning contexts have done. We suggest that measuring both performance and competence may remain insightful with quantitative data collected through surveys or graded assessments, even if students themselves conflate the two variables, but that qualitative approaches may find it more justified (and less confusing to participants) to discuss science efficacy as encompassing aspects of both performance and competence. We hope future research will continue to explore when and how it is useful to make distinctions between performance and competence.

We posit that high school students' definition of a scientist is a vital consideration in understanding how they develop their science identity. When a student's narrow definition of a scientist prevents them from connecting the act of performing scientific activities to being a scientist, this can limit their ability to see themselves as a scientist. Similarly, a limited concept of a scientist can inhibit the benefits of interacting with role model scientists, because the students may not readily be able to recognize these people as scientists. Previous research has examined how students' mental image of a scientist is impacted by gender and racial stereotypes, as well as stereotypes about what scientists wear and what type of science they do (Finson, 2002; Laubach et al., 2012; Miller, David et al., 2018). In adults, social group membership has been shown to influence who is and is not perceived as a scientist, as well as the scientific field of the person in question, especially if they have a PhD in a "hard" science like biology or chemistry (Suldovsky et al., 2019).

Previous scholars have noted that science identity development is strongly influenced by students' sociocultural identities and social context (Carlone & Johnson, 2007; Hazari et al., 2013; Kim & Sinatra, 2018; Lane, 2016; Rodriguez et al., 2017), and that one's science identity interacts with and is affected by racial, ethnic, gender, and other identities (Banks et al., 2016; Carlone & Johnson, 2007). For example, other researchers have found that the rifts between 'science person', 'a person who likes science', and 'a scientist', may be deeper for Black girls than for students of other identities, who may feel it is easier to move from enjoying science to thinking of themselves as scientists (Wade-Jaimes et al., 2021). Our study also provided evidence for the impact of sociocultural identities and contexts on science identity. In fact, the gender identities of researchers and educators in our program seemed highly relevant to the way students perceived these individuals as scientists (or not), which coincides with previous work on the role of the science teacher's own identity (Avraamidou, 2016).

Under the recognition component, our data supports the need to differentiate between recognition of self and recognition by others that has been discussed by previous scholars (Carlone & Johnson, 2007; Hazari et al., 2010; Hughes et al., 2021; Roberts & Hughes, 2022). The component we have defined as *recognition of self* is tied to previous research on self-efficacy, because self-efficacy beliefs incorporate recognizing one's own capabilities. Marginalized students, in particular, may struggle with building self-efficacy and recognizing themselves as a scientist, especially if their primary idea of self is as a student rather than as a scientist (Avraamidou, 2020; Flowers & Banda, 2016). Research shows the importance of self-efficacy for science identity, and especially the negative impact that navigating STEM spaces as a marginalized person has on students' belief in their own abilities regardless of their actual academic accomplishments (MacPhee et al., 2013; Rittmayer & Beier, 2009). Previous scholars have noted the importance of thinking and acting like a scientist for students' recognition of themselves as science people (Rodriguez et al., 2019). While students can develop recognition of themselves through noticing when they are acting like a scientist, we showed that if they are unaware that their actions are scientist-like then this could hamper their development of self-recognition.

We also have added support for the idea that recognition by others in the student's life seemed to be associated with stronger science identity. In our study, every student who expressed a strong sense of themselves as a science person also expressed that others recognized them as a science person. Our findings coincide with previous research such as Dou & Cian (2022), who found evidence for the importance of interactions with others in the development of science identity, especially support or lack thereof from people in the students' home environment. External recognition can be particularly important for marginalized students, who often experience a disparity in support and recognition for their science interest and ability as compared to their peers who fit adults' stereotypical notions of who can be a scientist (Stake & Nickens, 2005). Others have noted that there can also be disparities among students in the way recognition from educators occurs and whether this recognition is delivered publicly in a way that elicits further recognition by peers or remains a privately communicated recognition of the student directly by an educator (Hughes et al., 2021). Our findings, along with the previous research on the subject, suggest there is still much to explore in the way the recognition by others combines with recognition of self to impact science identity.

Considering recognition further, we added to our model a novel component highlighting the importance of recognition of others as scientists. Previous research has highlighted the importance of identity matching in potential role models (Andersen et al., 2014), and we expanded on this idea by noting the initial recognition of others as scientists as an important precursor to being able to see oneself in those potential role models. Previous research also supports the idea that interacting with experts that share demographic characteristics can build self-concept in STEM (Stout et al., 2011), but we note that this process breaks down if the student does not recognize the potential role model as a STEM expert. For example, stereotypes about scientists and stereotypes about gender can combine to create a sense of role incongruity when presented with the idea of a successful woman scientist or can even contribute to an implicit belief that women are deficient in the qualities needed to be effective scientists (Carli et al., 2016). Thus, expanding students' understanding of the traits that a scientist might possess and the types of tasks they might do, could allow students to imagine different types of people to fit into that role. Our finding about the role of recognition of others also underlines that providing students with exposure to potential role models that are meant to provide counterstereotypical examples of scientists from underrepresented groups needs to emphasize explicitly that these role models are successful scientists, and that their activities and traits exemplify what it means to be a scientist.

Additionally, we found evidence from our qualitative analysis to include *science interest* as a component of our model, in agreement with Hazari et al. (2010). Students in our program expressed science interest when describing disciplines or topics they enjoyed learning about, discussed means of science learning, and shared other things that they like related to science. Our interview protocol directly asked students, "*what type of career do you see yourself pursuing in the future?*", and we saw several students' express science interest in the context of their future plans and careers. Those ranged from a general interest in pursuing a scientific career, or interest in a specific profession related to science, to an acknowledgment that even non-science careers will benefit from an exposure to and understanding of science. Hidi & Renninger (2006)'s Four Phase Model of Interest Development considers that the highest level of interest (well-developed individual interest) is when a person chooses to continue to pursue a topic when given a choice. We argue that an interest in a science career or using science in their future careers shows that our students plan on reengaging with scientific topics even after they finish high school.

As we noted above in the findings, our analysis of the ways student's defined scientists revealed that students perceived "scientist" and "science person" as two distinct identities. This perception persisted even after the program, despite our encouragement for students to think of themselves as scientists during activities. The students' distinction between these two terms further highlights the importance of the student's definition of scientist in their conception of science of identity. These results are similar to Archer's (2010) findings with middle school students who distinguished between doing and enjoying science and being or seeking to become a professional scientist. During our program we used lesson material centered around participatory science projects and attempted to communicate that anyone who does science is a scientist. Our curriculum introduced the concept of participatory science, exposed students to the idea of citizen or community scientists, and offered the opportunity to become community scientists. We posit that identification first with an identity as a community scientist, or even a student scientist, may help students bridge the gap between their notions of science person and scientist, and expand their definition of scientist to encompass their own identity.

We also included in our model a dimension related to environment/community. Student science identity development is intricately linked to the context, topical content, and pedagogical choices of the learning environment. In crafting our curriculum, we sought to lead students to relate their scientific knowledge and skills to their own environment. Others have found that place-based education and authentic research are powerful tools in STEM education (Habig & Gupta, 2021; Sobel, 2004), and our results support a role for place-based education in science identity formation. We found that our curricular focus on place-based exposure science was especially helpful in inspiring students to connect their learning to the health of themselves and their families on a personal meaningful level. Further, our student-led participatory science approach coincides with Lave & Wenger (1991) concepts of situated learning and legitimate peripheral participation in which students engage in the same practices as experts but to a more limited degree. Science identity development does not happen in a vacuum, and we believe authentically incorporating real-life environmental context into our curriculum helped students absorb science identity into their understanding of themselves.

Conclusion

In returning to our initial research questions, our findings led us to several important modifications to Carlone and Johnson's science identity model (Figure 1). Our quantitative results showed an increase in students' perceived science efficacy through participation in our community-focused environmental participatory science program, and our qualitative analysis revealed the nuanced impacts of our program on other aspects of science identity as well. We also saw that participation in our program encouraged a sense of being a science person for some students, even though our efforts were somewhat curtailed by constrictive concepts of what it means to be a scientist. Lastly, we found that individual factors such as the amount of recognition by others a student has received correlates with the strength of that student's science identity.

Challenges and Future Directions

While our focused recruitment with specific schools and partners ensured that we reached a diverse student population (Table 2), our limited sample size of students with full data and IRB consent prevented us from drawing strong conclusions on the impact of individual students' sociocultural identities on their science identity. Interviews revealed some student experiences that were informed by the student's race and gender, and we hope future studies can explore these connections.

One of our key findings, that a student's definition of a scientist informed their understanding of science identity, calls for further investigation. We did not plan to focus on measuring students' definition of scientist in designing our qualitative or quantitative instruments, and we recommend that future research directly measures students' definitions of scientists and intentionally design programs that broaden students' understanding of who is (or can be) a scientist. Evaluating shifts in students' perceptions of scientists before and after program participation will provide valuable insights into the impact of a student's scientist definition on their science identity and can enhance science education program development. Future research could also continue to explore the impact of the distinction between a science person and a scientist, and how this gap may be limiting a student's ability to see themselves as a scientist.

Implications

We believe our results have implications for science educators interested in shaping a diverse scientific community and future STEM workforce. Educators can encourage science identity development by explicitly recognizing students' achievements, knowledge, and interest in science. Further, it is vital to uncover and challenge students' definitions of what it means to be a scientist. Actively redefining the term scientist and undertaking activities that broaden perspectives regarding who is a scientist, may allow students to more easily recognize potential role models as scientists, and eventually to see themselves as scientists. Our findings suggest that educators should emphasize how engaging in scientific skills and performing scientific activities are the crux of what it means to be a scientist. We also advocate for providing students with more opportunities to engage in participatory science activities with authentic research experiences that are connected to their own communities. We have provided our full curriculum and supplemental curriculum files for free use at the SIUE STEM Center website.

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Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary

Student Interview Protocol

Hello! My name is __________. I want to learn a little more about you. Are you okay talking now? [*Interviewer note: If you have not met or worked with the student before, please make sure to introduce yourself and your role on the program. Try to make this informal, so the student feels more comfortable speaking to you. If the student has not participated in an interview before, review the process with them. For example, tell them there are 12 questions, with some having multiple parts and that the interview will take about 15 to 20 minutes. Share that there are no "right" or "wrong" answers. Ask if they have any questions before getting started and if the student is okay with being recorded*]. **Are you okay with me recording our conversation?**

1. What did you like about being in the program? What was the most memorable part of the program?

2. Thinking back on the summer program, can you tell me about working with the scientists? What kinds of things did you do? What kinds of things did the scientist do? *If "no" ask if they have met scientists elsewhere. Tell me about it. What kinds of things did you do? What kinds of things did the scientist do?*

3. Do you feel like a **science person**? Why/why not? Do you feel like you are a scientist? Why/why not? What makes a person a scientist or a science person? *Probe: What do scientists look like or do? Probe: What is the difference between a science person and a scientist (if any)?*

4. How would you describe your feelings about science? *Probe: Interests; Value; Relevance*

5. Do you think other people [friends, family, teachers] think you're a **science person**? Do you think they think you are a scientist? Which other people? How do you know? *Probe: What do scientists look like or do? Probe: What is the difference (if any)? Would you like to be seen as a scientist/science person? How would this make you feel?*

6. Can you tell me some things you learned about the environment (both indoor and outdoor)? Can you tell me anything else that you know about the environment? What else would you like to know? *How about pollution and your environment?*

7. On a scale from 1-5, with 5 being the highest, how confident are you in using technology to communicate information about science (blogs, social media, websites)? What about using technology to do science (collect information, measure things)? Why did you pick # and not #-1, why not a #+1.

8. Can you think of some ways you could study the environment to help the people and places where you live, like your neighborhood, school, street, you live on, etc.? *Is studying your environment something you would feel confident doing?*

9. What are some things you learned about the environment where you live from the program sessions? What else would you like to know? What do you think other people who live near you would like to know? *Probe: Is there anything about the air, noise, soil, the human-built environment, pollution, etc. of your community?*

10. What type of career do you see yourself pursuing in the future? *Probe: Intentions of pursuing STEM or environmental science-related careers; Awareness of STEM or environmental science career*s.

11. What else would you have wanted to do in the program? *Probe: Is there anything else you wanted to do or learn about?*

12. Is there anything else you would like to tell me about the program, and what we have talked about today?

Codebook

Community Views: How the student sees how other people in their community views community
- Family: Influences from what their family says
- Viewpoints: their understanding of the community or understanding of how the community feels

Competence [knowledge and understanding of science content (may be less visible than performance)]
- Scientific competence: student's perception or expression of their science knowledge.
- Social media and online communication: student's expression of their knowledge and understanding of social media and other technology to communicate about science.
- Technology competence: student's perception or expression of their knowledge of technology
- Tools competence: student's perception or expression of their knowledge of scientific tools and instruments.

Environmental perspectives: How the student views and understands the Environment (big E environment here)
- Content knowledge - environment: their understanding of the environment
- Need to change: Students express the need to change the current environment, solution for changes, or the need to understand past environmental conditions
- Pollution: when the student talks about pollution in any sense.

Future careers: How the student views their future in education, jobs, and careers.
- Non-STEM: Career and/or future in a non-STEM field
- STEM (STEM to include medical jobs): Careers and/or future in an STEM field

Non-STEM interest: Student's description of their non-STEM interest, means of non-STEM learning, or other things that they like/like to do, excluding science.
- Learning, knowledge, and perceptions: Student's expression of the way they learn and how they perceive their abilities/attitudes/emotions in non-STEM areas.
- Non-STEM interest: Non-STEM interests the student has.

Performance: How the student views their ability to apply scientific knowledge and perform scientific tasks. (social performances of relevant scientific practices - e.g., ways of talking and using tools)
- Science tools/instruments: student's perception of their ability to use scientific tools and instruments.
- Scientific tasks: students' perception of their ability to perform scientific tasks or apply science knowledge exclusive of science tools or technology.
- Social media and online communication: Student's use of online tools like Zoom, Google meets, YouTube, TikToks and other platforms to communicate science.
- Use of technology for science: Student's view of using technology to perform scientific tasks.

Recognition (external and internal): How the student perceives others' view of them and their view of themselves (recognizing oneself and being recognized by others as a "science person")
- Attitude: their thoughts/feelings/emotions/attitude on what it would feel like to be recognized as a scientist (can be positive or negative)
- External recognition: the student expresses being recognized by others as a scientist/science person

- Internal recognition: the student internally acknowledges that they do or do not feel as though they are a science person.

Science identity: View of self as scientist and interest in science. When the student talks about themselves as a scientist or their interest in science.

- Expression of science identity: Attributes that indicate a student's degree of identity as a scientist.

Science Interest: Student's description of their science interest, means of science learning, or other things that they like related to science.

- Expression of science interest: Attributes that indicate a student's degree of interest in science.
- Learning, knowledge, and perceptions: Student's expression of the way they learn and how they perceive their abilities/attitudes/emotions regarding science/STEM.
- Student science interest: Science interests the student has.

View of scientists and/or science: How the student sees and understands scientists, and any past interactions or knowing of scientists.

- Appearance: student's view of what scientists look like.
- Interactions: student's description of the interactions with scientists.
- Scientists actions: student's understanding of what scientists do.
- View of science: Expression of how the student places views or value (negative, neutral, or positive) science and scientists

Pre-program and post-program long survey

Name: ______________________________________ Date: _____________________

Please answer the following questions by writing an X or check mark in the box. Remember, there is no right or wrong answer. We just want to understand what you think. If there is a question you do not want to answer, you do not need to. If you have any questions, please raise your hand and someone will help you out!

I am able to…	**Strongly disagree**	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
Create a science project to answer a question about the environment.					
Use data to explain things about my environment.					
Record measurements using different kinds of monitors and tools.					
Collect measurements that help answer questions about my environment.					
Understand how the data I collect contribute to science.					
Share my research findings with my friends.					
Share my research findings with people in the community.					

Please answer the following questions by writing an X or check mark in the box. Remember, there is no right or wrong answer. We just want to understand what you think. If there is a question you do not want to answer, you do not need to. If you have any questions, please raise your hand and someone will help you out!

In the past, I have worked with others to...	**Never**	**Rarely**	**Sometimes**	**Often**	**Always**
Create a science project to answer a question about the environment.					
Use data to explain things about my environment.					
Record measurements using different kinds of monitors and tools.					
Collect measurements that help answer questions about my environment.					
Understand how the data I collect contributes to science.					
Share my research findings with my friends.					
Share my research findings with people in the community.					

Please answer the following questions by writing an X or check mark in the box. Remember, there is no right or wrong answer. We just want to understand what you think. If there is a question you do not want to answer, you do not need to. If you have any questions, please raise your hand and someone will help you out!

Other people, like my teachers, parents, and friends, notice that I can …	**Never**	**Rarely**	**Sometimes**	**Often**	**Always**
Create a science project to answer a question about the environment.					
Use data to explain things about my environment.					
Record measurements using different kinds of monitors and tools.					
Collect measurements that help answer questions about my environment.					
Understand how the data I collect contributes to science.					
Share my research findings with my friends.					
Share my research findings with people in the community.					

Please answer the following questions by writing an X or check mark in the box. Remember, there is no right or wrong answer. We just want to understand what you think. If there is a question you do not want to answer, you do not need to. If you have any questions, please raise your hand and someone will help you out!

	Strongly disagree	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
I am a science person.					
I am a scientist.					
Other people think I'm a science person.					
I feel like I fit in with others in the world of science.					
I can see myself doing the work of a scientist.					

Please answer the following questions by writing an X or check mark in the box. Remember, there is no right or wrong answer. We just want to understand what you think. If there is a question you do not want to answer, you do not need to. If you have any questions, please raise your hand and someone will help you out!

	Strongly disagree	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
I plan to go to college.					
I plan to study science in college.					
I plan to study about the environment in college.					
I will get a job in a science-related area.					
I will get a job in an environmental science-related area.					
I would enjoy a job in science.					
I would enjoy a job in environmental science.					

Name: ____________________________________

What grade are you starting this coming school year?: ______________________________

Age: ___________________________

I am (circle your choices): *Female* *Male* *Non-binary* *Other:*_________________

I am (circle all of your choices): *American Indian* *Alaska Native*

Asian American African American *Black* *Hispanic* *Latino/a*

Native HawaiianOther Pacific Islander *White* *Other:* _________________

Repeated measures short survey

Name: ______________________________ Date: ________________________

Please answer the following questions by writing an X or checkmark in the box. Remember, there is no right or wrong answer. We just want to understand what you think. If there is a question you do not want to answer, you do not need to. If you have any questions, please raise your hand and someone will help you out!

	Strongl y disagre e	**Disagr ee**	**Neither agree nor disagree**	**Agre e**	**Strong ly agree**
I see myself as a science person.					
Being a science person is important to me.					
I think of myself as a science person.					
I am a science person.					
I am a scientist.					
In general, being a science person is an important part of who I am.					
Knowing more scientists with a similar background as mine makes me feel more like a science person.					

Mark the picture below that best describes the overlap of the image you have of yourself and the image you have of a science person.