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Successes and Limitations of Inquiry-Based Laboratories on Affective Learning Outcomes for Deaf, Hard-of-Hearing, and Hearing Signing Students

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Abstract: Active learning pedagogies such as inquiry-based learning have the potential not only to improve students' science literacy but also promote affective learning and interest in science, technology, engineering, and mathematics (STEM) careers. Moreover, a focus on affective learning may be key to improve recruitment in STEM. Yet, we know little about how participation in inquiry-based courses can impact college students' affective learning. Here, we present results from a comparative analysis of two affective learning outcomes, attitudes toward science and science identity, after participation in inquiry-based laboratory courses. Then, we synthesize what we have learned about successes and limitations to promoting growth in positive attitudes toward science and science identity after participation in these courses. Our work focuses on non-science majors who are deaf, hard-of-hearing and hearing signers in bilingual (American Sign Language and written English) inquiry-based biology laboratory courses. We concentrate on the Deaf Community because deaf individuals often face challenges regarding access in STEM education. Our results indicate that participation in inquiry-based laboratory courses has the potential to positively influence students' attitudes toward science via repeated engagement with hands-on, student-driven experimentation, peer collaboration, and a welcoming classroom environment. However, participation in these classes had a limited impact on students' science identities. Some students saw themselves as scientists during laboratory classes, however, their science identities beyond the classroom remained unchanged. While inquiry-based laboratories successfully promote one aspect of affective learning, work is needed to improve students' science identities and increase interest in STEM careers to more effectively recruit students in these courses.

Keywords: STEM, Deaf, inquiry-based laboratory classes, affective learning, attitudes toward science, STEM careers, science identity.

Introduction

Active learning pedagogies such as inquiry-based learning can improve students' science literacy and science process skills (Gehring and Eastman, 2008; Gormally *et al.*, 2009). These pedagogies may also promote affective learning and interest in pursuing science, technology, engineering, and mathematics (STEM) careers. Students may make gains in affective learning after participation in inquiry-based laboratory courses because they "engage in many of the same activities and thinking processes as scientists" (National Research Council, 2000). In inquiry-based laboratory courses, students are challenged to develop research questions, collect data to evaluate hypotheses, formulate explanations using scientific understanding, and interpret and communicate their findings (National Research Council, 2000; Weaver et al., 2008; Beck et al., 2014). As a result, students become more responsible for their learning (Gormally *et al.*, 2011; Gormally *et al., 2*016). Increased responsibility and autonomy for learning may enhance students' interest in science (Partin and Haney, 2012). For example, students in K-12 classrooms demonstrated improved attitudes toward science after participating in inquiry-based learning (Gibson and Chase, 2002 and references therein). Participation in inquiry-based laboratory learning could also challenge students' perceptions of scientists and their conceptions of themselves as "science people." After doing science themselves, students might perceive scientists less stereotypically, and come to see themselves as competent in doing science. Thus, students' science identities might be improved after participation in inquiry-based learning. Yet, we know little about whether college students make gains in affective learning outcomes, including growth in positive attitudes toward science, science identity, and increased interest in STEM careers after participation in these courses.

The development of positive attitudes toward science is critical both for successful science learning in the classroom and long-term engagement with science (Koballa and Crawley, 1985; Feinstein *et al.*, 2013). Attitudes toward science can be defined as the "feelings, beliefs, and values held about an object which may be the enterprise of science, school science, the impact of science on society, or scientists themselves" (Osborne *et al.,* 2003). Attitudes are learned predispositions, which grow and change through years of science learning experiences (Koballa and Crawley, 1985). Notably, students' attitudes toward science can affect how they approach science learning (Osborne *et al.*, 2003; Semsar *et al.*, 2011) since their desire to learn and to succeed in the classroom is connected to these attitudes (Koballa and Crawley, 1985). Likewise, negative attitudes toward science can lead to underperformance (Schiefele *et al.*, 1992).

College students who participated in an inquiry-based biology laboratory course made gains in affective learning outcomes, including boosts in their confidence and interest in science (Jeffery *et al.* 2016). In only one semester, students developed significantly more expert-like attitudes toward science (Jeffery *et al.* 2016). Importantly, these effects even applied to students with low academic performance or little English-language experience. These results suggest that participation in opportunities for active engagement in doing science, afforded by inquiry-based laboratory courses, can positively impact students' affective learning, including students from diverse backgrounds.

Science identity is another important area of potential growth for students in inquiry-based laboratory classes. Science identity is defined as the authoring of one's identity in relation to science and the feeling of belonging with science (or not) (Johnson *et al.* 2011). For example, if a student views herself as fascinated by science and/or proficient in science, she may perceive herself as a "science person." However, if students do not identify as "science people," they are unlikely to pursue STEM degrees (Diekman *et al.,* 2010; Losh, 2009). A student's science identity may be based on years of patterns of participation, attitudes, and expectations about science learning (Archer, Dewitt, & Osborne, 2015; Carlone & Johnson, 2007). Like all aspects of identity, science identity is malleable to change (Gee, 2000).

Science identity also involves aligning one's identity with one's understanding of who scientists are, to decide if one belongs (or not) with a potential STEM career path (Diekman *et al.,* 2010). Many people associate science fields with stereotypical conceptions of scientists such as the nerdy, socially awkward white man in a white coat who is completely focused on science (Finson, 2010). When a student accepts this stereotype, she effectively precludes her potential interest in a STEM career as her self-perception does not align with her perceptions of who scientists are; thus, for her, a STEM career is unimaginable (Losh, 2009). These stereotypes disproportionately affect women, people of color, first-generation students, and students of low socio-economic status, all of whom tend to highly value altruistic career goals, but who do not perceive STEM as affording opportunities to satisfy altruistic goals (Allen *et al.,* 2015; Brown, Thoman, Smith, & Diekman, 2015; Diekman *et al.,* 2010; Thoman, Brown, Mason, Harmsen, & Smith; 2015). Moreover, cultural communities (*e.g.,* Latino and Native

American communities (Thoman *et al.,* 2015)) often encourage the pursuit of altruistic goals that benefit one's community. Unfortunately, students who hold both stereotypical conceptions of scientists and altruistic career goals may not be interested in STEM careers, especially those students from diverse cultural groups (Brown *et al.,* 2015). In effect, preconceived stereotypes about science may be a barrier to recruitment in STEM (Diekman *et al.* 2015). Thus, focusing on students' potential growth in the affective domain may be key to improving recruitment in STEM.

Here, we present a comparative analysis of two affective learning outcomes from what we have learned from recent qualitative studies about participation in inquiry-based laboratory courses (Gormally 2017; Gormally & Marchut 2017). This comparative analysis stems from qualitative studies focused on non-science majors who are deaf, hard-of-hearing and hearing signers in bilingual (American Sign Language and written English) inquiry-based biology laboratory courses. Many deaf and hard-of-hearing individuals consider themselves members of the culturally Deaf community, which shares traditions, language, and values, including giving back to the community (Clark & Daggett 2015). Prior research suggests that students who consider themselves to be part of the Deaf community may not see STEM as affording opportunities to give back to the Deaf community (Gormally & Marchut 2017). In this manuscript, we explore and compare the differences in students' attitudinal growth versus science identity development after participation in inquiry-based biology laboratories. Specifically, we asked:

> How do students' attitudes toward science change in comparison to their science identities, after participation in inquiry-based biology laboratory classes?

We discuss the role of college inquiry-based learning in promoting gains in the affective domain, what we have learned about successes of inquiry-based learning, areas for instructors to consider so improvements can be made to support student growth, as well as limitations to this pedagogical approach.

Methods

We conducted end-of-the-semester semi-structured individual interviews with students from inquiry-based biology laboratory courses (N=15) during three semesters (Spring 2015, Fall 2015, and Spring 2016). The interview protocol was developed using literature on science identity (Varelas, 2012) and attitudes toward science (Osborne *et al.*, 2003; Semsar *et al.*, 2011). We piloted the interview protocol in ASL with three deaf students. During pilot interviews, students were asked to explain their understanding of the questions, explain their responses, their reasoning for their responses, and comment on the question wording. After each pilot interview, we refined the interview questions, removing and adding questions based on what we learned.

Interviews, approximately 30-45 minutes, were videotaped and conducted in the interviewee's preferred language (ASL or English). The authors conducted the interviews together. Interviews focused on understanding students' perspectives about their experiences in biology laboratory class and how these experiences impacted their attitudes toward science and science identities. Interviews began with questions to understand students' prior science learning experiences. Subsequent questions explored students' perspectives about their self-conceptions as a science person, experiences in the inquiry-based biology laboratory class, and perceptions of the relevancy of laboratory learning to everyday life. The authors individually developed written English translations of interviews as needed, using ELAN (tla.mpi.nl/tools/tla-tools/elan/). Then, the authors discussed each translations until reaching agreement. Translated scripts were imported into Excel for coding.

The translated interviews were coded with the research questions in mind: How does participation in an inquiry-based laboratory course impact students' attitudes toward science? How does participation impact students' science identity? The research questions were used to guide the inductive coding process. The coding process involved iterative cycles. The authors individually coded the interviews to identify categories, then aligned their codes through a series of meetings. During meetings, the authors compared how their coding classifications converged and diverged, and discussed codes until reaching agreement, using *in vivo* coding to capture participants' voices where feasible (Corbin and Strauss, 2008; Saldaña, 2013). Through this coding process, patterns and themes in the data emerged.

We then focused on comparing gains from the different types of affective outcomes: students' attitudinal growth versus students' science identity development. We categorized students according to three types of attitudinal growth (positive attitude or remained positive; neutral attitude; or negative attitude). We categorized students' science identity development into four groups, based on analyzing the number of students who (1) did not see themselves as scientists either inside or outside of the laboratory classroom; (2) saw themselves as scientists during laboratory class; (3) saw themselves as scientists both inside and outside of laboratory class; and (4) students whose science identity was unclear. We present the results of this comparative analysis.

Efforts to ensure study validity

Conducting interviews together allowed us to capitalize on follow-up questions to probe deeply to uncover students' experiences. We were vigilant in our efforts to capture participants' voices accurately, discussing interview translations in depth, and using *in vivo* coding to capture participants' voices when possible. Since we translated the interviews individually, we could compare translations and identify any differences, which were uncommon, but which we discussed until reaching agreement. Finally, the manuscript was shared with research participants to check their understandings with the conclusions, listen to their comments, and incorporate their feedback. This member-checking enriched the data analysis and validity (Patton, 2002).

IRB Approval

The project was granted IRB approval by Gallaudet University Institutional Review Board (Proposal #2520) after expedited review.

Results

Positive attitudinal growth

The majority of students developed positive attitudes toward science (or remained positive) after participating in inquiry-based biology laboratory classes (Table 1). At the end of the semester, students expressed that they were more motivated to research questions related to science in their own lives and that they believed science was relevant to their lives. Students also commented that they realized they could be successful in learning science.

Table 1. Students' attitudes toward science after participation in inquiry-based laboratory classes.

Attitude toward science (N=17)	Themes related to attitudes	Student Quotes
Positive attitude (12), including: Positive growth (10) or remained positive (2)	• "Science applies to my life"	• "I feel like [learning science] really benefits us because we can understand what is going on in news."
	• "I'm more motivated to research scientific questions related to my life."	• "I'm more interested in how human bodies perform, how they can move, how they can change." • "Yes, some experiments made me want to know more about the topic." • "I have an improved understanding of the concept of science methods; how to put together data. I understand that much better now and I'm interested in science."
	• "I can learn biology."	• "Now I understand how to do experiments and write lab reports, how I should show information and give details about information and at the same time don't try to explain them in simplest way…"
Neutral attitude (1)	• "My attitude about science is still neutral."	• "It was almost the same class I took back in HS, so I already have a good understanding of how human bodies work, because in HS I took this class, I already had an understanding of what the class would be about."
Negative attitude (2)	• "Science classes are a waste of my time." • "What I learned isn't useful for other classes or my life."	• "I don't really think about biology outside of class. I know biology is required for my major in interpreting, but I don't really see how it is related."

We identified three major themes related to students' development of positive attitudes toward science. The first theme was that students perceived that "science applies to my life" after participating in laboratory class. Students often described learning skills and information in the laboratory class that applied to their daily lives as well as their future careers. For example, one student explained that he recognized the value of learning about genetics for making decisions about the use of genetic information and testing in his life. The student explained:

> One time I was talking with-- I'm a manager--I was talking with a worker, and she was talking about her mom and genetics because she had noticed that all of her siblings had dimples. She recently discussed that, which was interesting, her mom had dimples, but her father did not. That mean the gene was dominant. She found that interesting so, yeah, I could say that I use that information in real life.

This is one example of how students apply what they have learned from the inquiry-based laboratory course to their lives. When asked if inquiry-based laboratory activities were beneficial, a student stated, "I feel like it really benefits us because we can understand what is going on in news" and another student stated, "it applies to my future-- to be able to do psychology research." These examples demonstrate how some students applied what they learned to their daily lives and their majors. As students learned more about the practical aspect of doing science, they could better understand the sociocientific issues discussed in the news. Furthermore, some students benefitted from learning how to create and conduct an experiment as they could then apply those skills to other courses and their future career.

The second theme was that students recognized "Biology is not what I thought it was." More specifically, students' perceptions of what doing science entails shifted after doing science themselves. For instance, a student noted that her understanding of the scientific research process changed, explaining:

> That [the research process] doesn't always go boom boom boom, that there can be mess-ups…it's not just 1, 2, 3, you can go back and forth, it's not linear. You might spend three days on the experiment and the data before you even get to your results.

Students also commented that they found themselves enjoying doing science in laboratory class, as well as developing a newfound appreciation for the role of scientific research in learning about life around us. Students frequently commented that they expected to find the biology laboratory class "boring," but discovered that they found the class enjoyable as the semester progressed. Through designing and conducting their own experiments in an inquiry-based laboratory course, most students' attitudes towards science improved.

Finally, we identified a third theme: students discovered that "I can successfully learn biology." Students explained that they began the semester with little confidence in their ability to learn science. However, after participating in the laboratory class, students realized they could be successful at learning science. For example, one student explained:

> I feel like [participating in lab class] built up my confidence…when I put up graphs on the board to show an example everyone was like, "yes, that's perfect." That's stuff that made me feel good as a student…Before class, I was like "I suck at Biology."

A student said the following, "I have an improved understanding of the concept of science methods; how to put together data. I understand that much better now and I'm interested in science."

Likewise, another student stated, "Now I understand how to do experiments and write lab reports, how I should show information and give details about information and at the same time I don't try to explain them in simplest way." These statements reflect positive attitudinal growth, as students believe they have a better understanding of how to conduct an experiment to investigate a particular question or problem. Many students expressed positive attitudes about their ability to learn biology after participating in the laboratory course.

Our analysis suggests that students' attitudinal growth is driven by three factors: students perceiving laboratory activities as valuable learning experiences, repeated direct engagement in scientific inquiry, and peer collaboration. Students appreciated engaging in doing science themselves--actually designing and carrying out their own experiments, with support from their instructor, and saw peer collaboration as critical to making this experience successful. One student explained:

> [The lab] helped me work with students in groups, the lab had a lot of group work. [Group work] helped me with understanding lab more--lab reports, how to do that right and how to develop a hypothesis...just [by] asking questions to different people and talking to students. [This] helped me become a better student.

Students worked in groups, working together to design and conduct their own experiments. As a result of working together through the process of developing experiments, students learned about the actuality and different aspects of doing science. Students noted that the benefits of working in a group included asking each other questions and collaborating on doing science. Participation in inquiry-based laboratory in this study demonstrates how the three factors impacts students' attitude towards science.

Limited science identity development

However, in contrast to this positive attitudinal growth, students' science identity development was limited. While some students saw themselves as scientists during class, the majority of students failed to see themselves as scientists beyond the classroom (*Figure 1*). Interestingly, while students were engaged in doing science themselves in the laboratory classroom, mimicking the activities that scientists undertake (e.g., designing experiments, collecting and analyzing data, discussing how to interpret data, seeking feedback and multiple perspectives about their work), this did not translate to significant changes in their science identities. More importantly, this experience did not translate beyond the classroom. Participation in an inquiry-based laboratory course ultimately had a limited impact on students' science identity development.

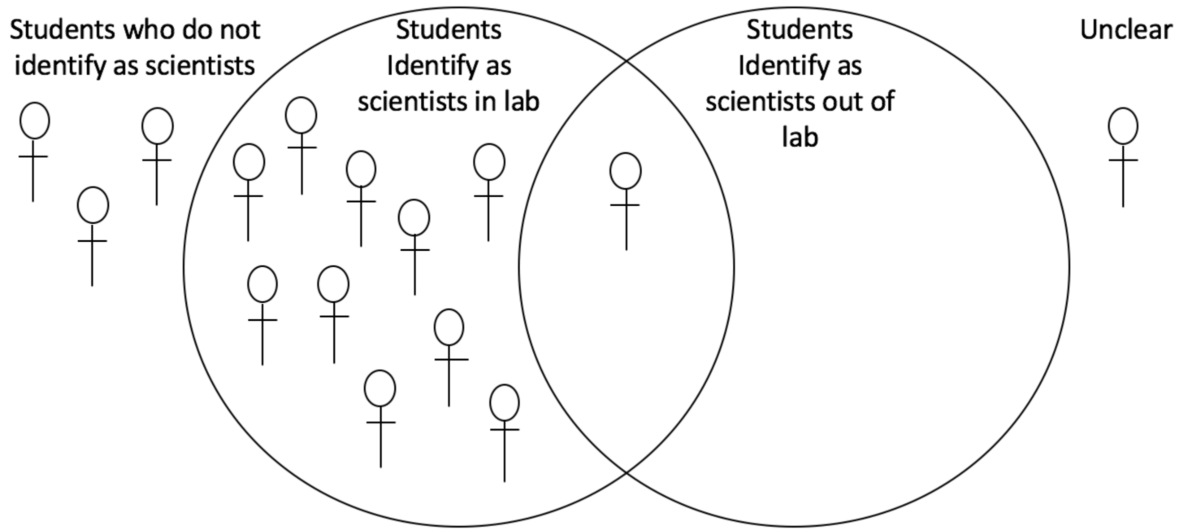

Figure 1. **The number of students who did and did not see themselves as scientists, in and beyond the laboratory classroom.**

Four major themes explain why students' science identities remained mostly unchanged. First, students often held stereotypical conceptions of scientists, describing scientists as wearing white lab coats, working in isolation in their laboratories. For instance, when asked what image came to mind, a student responded:

> A person with a white coat or jacket... Stereotypical, you know, in the lab, with no windows, researching, doing something, transferring [or] pipetting something small, whatever, or counting something, writing on paper.

This is an example of how stereotypes about scientists--who they are--and what doing science is like-- are still prevalent amongst students. These persistent stereotypical perceptions may have a negative impact on students' willingness to perceive themselves as scientists.

Secondly, students often described scientists as highly intelligent people with deep content knowledge in science. Students' visions of scientists as isolated, highly intelligent individuals likely did not align with their self-perceptions. During an interview, a student said:

> I think scientists are very intelligent; they should know everything--how to do research, invest time to find out more about life out there. [Doing] lab research, testing.

However, a few minutes later, she said:

> But myself as a scientist? No. I'm not interested in human biology…such complex information. I feel like I want to avoid it. I like social work. That's my thing.

This student's explanation is an example that demonstrates how students often perceived scientists as being brilliant. Their self-perceptions did not align with their conceptions of scientists. Consequently, students might not perceive themselves as belonging with science or being science people.

An additional two themes were closely related to each other: students did not perceive science as a career that helps others or being connected to people; and students often expressed that "science is not my thing." When asked to elaborate, students explained that they decided not to major in science because their career interests fit better with their experiences growing up. These were experiences that triggered their interest in their particular major. Science, they explained, did not fit their personality. For instance, a physical education and recreation (PER) major student responded to the question about why she did not decide to major in science:

> Because I'm not fascinated with science, because I can't envision myself as a scientist or whatever. That's not me. My vision [for myself] is different, it's about other things…I can envision myself as a PER teacher but not as a scientist. Me, I'm an athlete, I love sports. I'm involved in different sports--I play basketball, cheerleading, track...so myself as a scientist, no. If someone had encouraged me to learn science when I was growing up, that would have been my thing, I would be fascinated with science. But no one did. I was never exposed to a lot of science in my high school, just the basics.

This quote shows how the experiences growing up can influence a student's career choice based on positive experiences and associations, and especially if they do not perceive themselves as scientists. Given the themes we identified, we suspect that students' science identity development may be limited because their perceptions of science and scientists were not sufficiently challenged by the inquiry-based laboratory class (Table 2). While students received a glimpse of what doing science is like from participating in inquiry-based science learning, they still did not perceive science as affording altruistic goals. The inquiry-based laboratory curriculum did not emphasize the opportunities in science to realize one's altruistic goals and give back to one's community. As a result, students' science identity development may have been limited by their perceptions that science does not afford altruistic goals.

After participating in a one-semester inquiry-based laboratory class in which students worked in groups to collaboratively develop and conduct experiments, most students developed a positive attitude towards science. This positive shift resulted from students realizing they could learn science, that science could be used in their daily lives, and that learning about science was worthwhile (Table 2). Although students developed positive attitudes towards science, most students' science identities did not shift. The majority of students' conceptions of scientists, which were stereotypical at the beginning of the semester, broadened as they participated in the typical activities scientists partake. Some began to perceive themselves as scientists in the lab, however, this perception did not extend outside of the lab. Many did not see themselves as a scientist outside the laboratory class because they did not see their altruistic goals or career interests aligning with their perceptions of what it means to be a scientist. Overall, students' attitudes toward science appeared to be more malleable as compared to their science identities.

Table 2. Outcomes related to affective gains after participation in inquiry-based laboratory classes. Positive outcomes are indicated by x. Themes related to outcomes are described.

	Themes / Positive outcomes		**Reasons for Outcomes**
Attitudinal growth	Viewing science learning as do-able	x	• Repeated engagement with experimentation • Peer collaboration • Supportive classroom environment
	Identifying science as relevant to life	x	
	Valuing learning science	x	
Science identity growth	Perceiving scientists non-stereotypically	x	• Doing activities similar to those that scientists do (writing, thinking, questioning, designing experiments)
	Perceiving self as a scientist in the laboratory classroom	x	• Conducting experiments themselves that were relevant to their interests
	Perceiving self as a scientist outside of the laboratory classroom		• Students' self-conceptions did not align with their stereotypical conceptions of scientists
	Seeing science as a potential career path		• Viewing science careers as not affording altruistic goals • Pursuing other career paths due to greater interest

Discussion

The goal of this study was to investigate the impact of inquiry-based laboratory learning on non-biology major students' attitudes towards science, and their science identities, including their conceptions of scientists. Here, we summarize findings from a comparative analysis of students' science identities and their attitudes toward science. More students made changes in their attitudes toward science in comparison to their science identities over the course of the semester. Ten of the fifteen students demonstrated a more positive attitude. However, most students' science identities (N=9) were only changed in the classroom, not outside of the classroom; in fact, only one student perceived himself as a scientist both inside and outside the laboratory classroom. And, unfortunately, three did not see themselves as scientists either in or outside the laboratory classroom. Yet, to recruit students into STEM, students' self-conception as scientists must be actualized in contexts beyond the classroom. Our findings suggest that participation in inquiry-based laboratory classes resulted in greater attitudinal changes than identity changes. Attitudes toward science may be more malleable than students' science identities. This is an important consideration regarding students' affective learning outcomes in STEM.

Our results indicate that more work is needed to challenge students' science identities, in order for students to see their self-conceptions align with their conceptions of scientists. The results of our comparative analysis show that most students saw themselves as scientists while participating in inquiry-based laboratory activities—which is a step in the right direction. However, this is just the beginning if introductory inquiry-based laboratory classes are to be excellent opportunities to recruit students to STEM majors. Students felt like scientists when they were involved in the process of designing and conducting their own experiments. In particular, students commented that working as a team with their peers to troubleshoot experiments, without the instructor's direction, was empowering. In those moments, students described that they felt like scientists. But this vision of themselves as scientists never extended beyond the classroom. Ultimately, students' fundamental science identities and interest in majoring in STEM fields remained unchanged. Participation in laboratory activities that closely mimic real science was simply not enough to challenge students' science identities.

Future inquiry-based laboratory classes might incorporate examples of working scientists to challenge students' perceptions about who scientists are (for example, following recommendations from work by Schinske *et al.,* 2015) and to reflect the growing diversity of scientists, as well as reflective discussion about what it is like to be a scientist. We also recommend that faculty emphasize the altruistic goals inherent in STEM in order to change students' often-stereotypical perceptions about STEM careers--stereotypes which often preclude interest in STEM careers (Finson, 2010; Losh 2009). Since some cultural minority groups (e.g., Latino, Native American, and the Deaf community) value careers that afford opportunities to give back to their communities, elaborating on explicit connections between science and these communities may increase interest in STEM careers Allen *et al.,* 2015; Brown *et al.,* 2015; Diekman *et al.,* 2010; Thoman, *et al.*, 2015). More work is needed to challenge students' science identities and improve interest in STEM careers if these types of courses are to increase recruitment into STEM majors. Continuing research about how active learning pedagogies impact students' affective learning outcomes may provide important insights for improving recruitment and persistence as well as helping to broaden diversity in STEM. This is especially important for students from underrepresented groups in STEM, and minority cultural groups, including this study's population—deaf and hard-of-hearing students (Walter, 2010; Solomon *et al.* 2013, NSF 2015).

The results provide a glimpse into inquiry-based learning in a STEM laboratory course, affective learning outcomes in undergraduate STEM education, and students' attitudes toward science and their science identity, and how they may be connected. Inquiry-based learning appears to have a positive influence on students' attitudes toward science but a more limited impact on students' science identities in laboratory classes. Future investigations across a longer time period, with a greater sample size, might allow us to better understand how students from different demographic groups may be impacted by inquiry-based learning. Continuing these types of investigations is essential if we want to promote more positive perspectives regarding science, who scientists are, and STEM careers. A better understanding of how evidence-based pedagogies such as inquiry-based learning impact the affective domain of learning is needed to increase recruitment and retention in STEM disciplines.

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