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Navigating learning ecosystems: Exploring students' use of agency in marine and environmental sciences

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ABSTRACT

This case study shares feedback from program alumni who are from underrepresented groups in STEM and who participated in either an undergraduate internship program or a Bridge to Ph.D. program designed to broaden participation in the marine and environmental sciences. The internship program was hosted by a Historically Black College and University (HBCU), in partnership with local collaborators who hosted students. The Bridge to Ph.D. program was co-designed by faculty leaders from the HBCU and faculty partners at a primarily White institution (PWI) who hosted the program on their campus. Interviews were conducted one to four years after participation in one of the programs to learn whether students were still involved in the geosciences and to document the ways they used agency to navigate the marine sciences learning ecosystem. Almost all students were still engaged in the marine and environmental sciences, and all were still engaged in STEM fields. The agency included in their stories reiterates themes from the literature and demonstrates a range of successful pathways that can be encouraged and supported by those striving for inclusion in the geosciences. Results are described in relation to the importance of changing the shared social practices utilized within the geosciences to support inclusion, particularly regarding how success is defined.

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Introduction

Geosciences have historically been considered one of the least diverse STEM fields and have shown little improvement in recent decades (Bernard & Cooperdock, 2018). This lack of diversity has been associated with low student persistence due to isolation and having to navigate unsupportive and sometimes hostile environments (Clancy et al., 2017; Clancy et al., 2014; Mattheis et al., 2019). Over several decades, researchers have examined broadening participation programs and institutional cultures' ability to recruit, support, and retain underrepresented minorities (URM) in the geosciences (see Mattheis et al., 2019 for a recent synthesis). One branch of research has examined the importance and success of minority-serving institutions (MSIs) and Historically Black Colleges and Universities (HBCUs) in the recruitment, retention, and graduation of URM geoscience students (Bililign, 2019; Chigbu et al., 2007; Robinson et al., 2007). Historically, HBCUs have been successful at retaining and graduating students utilizing "best practices" such as intensive mentoring experiences with faculty and peers, peer tutoring, supplemental instruction and summer bridge courses and student-Faculty research (Bililign, 2019; Roach, 2015). Still, there are calls for additional research on how their practices can inform programs at predominantly White institutions (PWIs) (McDaris et al., 2017; McGee, 2020).

Simultaneously, there has been a call for more research on the characteristics of students that benefit from these programs (Callahan et al., 2017). Student agency, or their sense of control over the way in which they participate in various experiences (Secules et al., 2018), is crucial for navigating learning ecosystems that provide a range of opportunities, as well as choices to persist in or leave a field of study. Studies that have examined STEM students' agency have looked at it as a response to navigating unsupportive academic cultures (Gallard Martinez et al., 2019; Godwin & Potvin, 2017; Hodari et al., 2016; Ko et al., 2014; Ong et al., 2018; Secules et al., 2018).

University of the Virgin Islands (UVI) students that participated in a community-based internship for undergraduates or a Bridge program for graduate students were interviewed about their journey as scientists and how their involvement in the program influenced their trajectory, recalled their use of agency in pursuit of their educational and career goals. In this study, their stories are described

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in relation to a learning ecosystem model to document the role of student agency, which may be hidden in both the pipeline and pathway models traditionally used to describe student success (Batchelor et al., 2021; Lord et al., 2019).

STEM learning ecosystems

The use of the term "ecosystem" in education is often linked to Uri Bronfenbrenner's ecological perspective of development (1979), which was the first to define a child's environment in terms of an ecosystem. Years later the idea of a STEM learning ecosystem was created through an application of Bronfenbrenner's theory to interest and learning in technology education (Barron, 2006). Since that time, the model has been applied more broadly to explore all disciplines involved in a STEM learning ecosystem (Allen et al., 2020; Barron, 2014; National Research Council, 2015; Traphagan & Traill, 2014), with the most recent addition illustrating workforce development within STEM learning ecosystems through the metaphor of a braided river (Batchelor et al., 2021). This latest analogy demonstrates "inclusive, responsive, and modern career development" within the geosciences by recognizing the various pathways that are indicative of success within the STEM workforce. This paper includes the early success stories of marine science program participants who were supported in navigating their learning ecosystem.

The braided river analogy depicts learning ecosystems as a landscape that includes a range of opportunities (Figure 1). The notion of multiple pathways toward a wide range of successes is particularly relevant for the current paper, which focuses on the ways that students use agency to navigate their learning ecosystem to achieve their educational and career goals. Hecht and Crowley (2020) note that learning is "a process that exists because of the interactions between learning ecosystems and actors" (p. 268) such as students and educators, as well as the local and departmental cultures that make up a complex adaptive system. When applied to Hecht and Crowley's ideas, we believe the braided river as a geographical system provides a snapshot that depicts the complex, adaptive educational systems that students navigate to pursue their educational and career goals. As such, the entire landscape rather than individual programs can and should be the focus of study. This study explored this perspective by conducting retrospective interviews with students to gather stories about how they had navigated their learning ecosystem Braided rivers are those that include a network of branches within a channel. Following Batchelor et al. (2021), we define our channel as the marine sciences

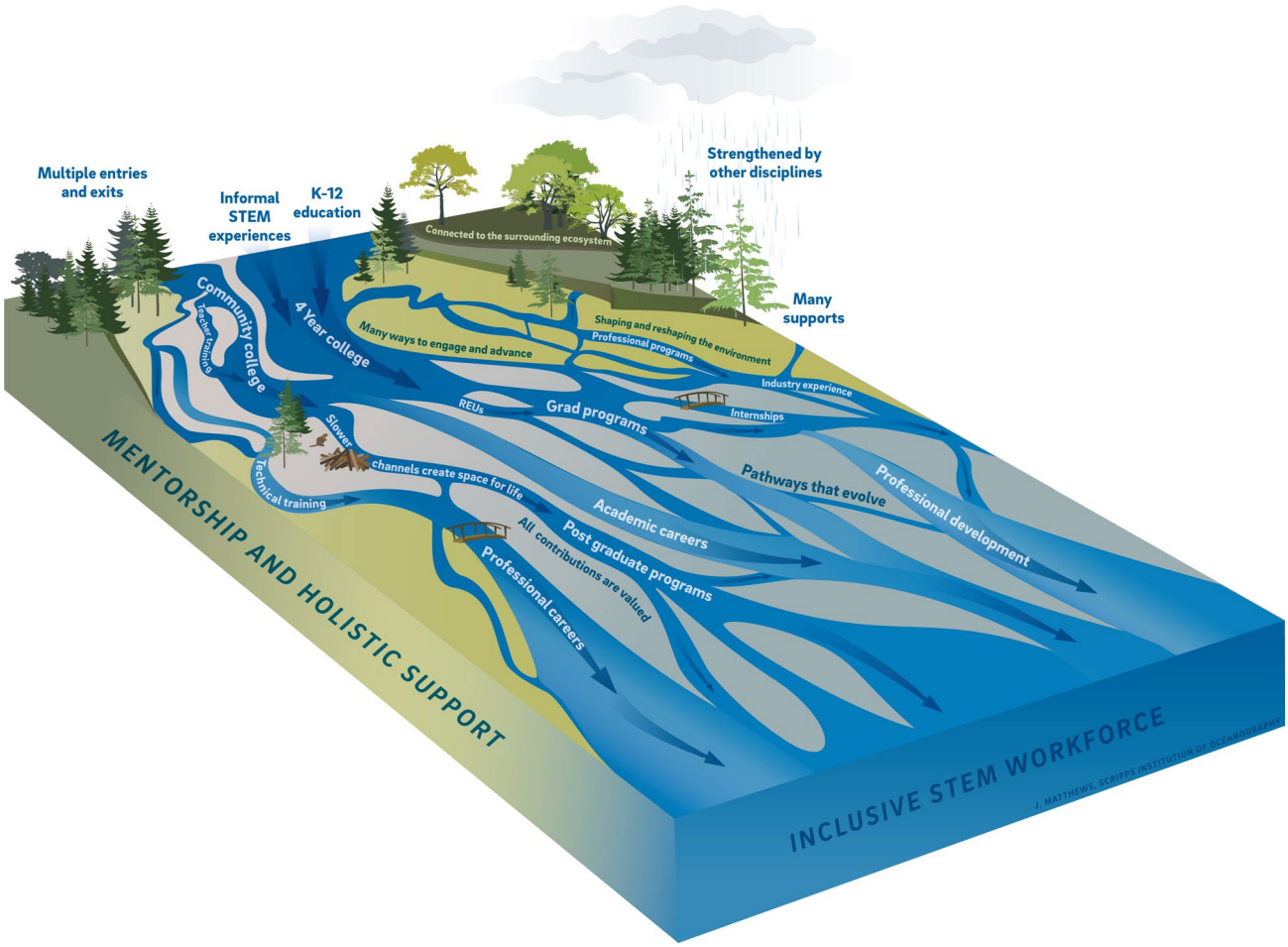

Figure 1. A braided river illustration of a holistic STEM workforce career development model. Figure reproduced from Batchelor et al. (2021) with permission. Image by J. Matthews, Scripps Institution of Oceanography.

broadly and the branches as the specific learning opportunities available to students.

Student agency in STEM

Case studies and longitudinal methods are typically used to examine URM student agency in STEM contexts through the perspective of coping, persistence, and strategies used to navigate isolating environments; for example, examining the use of "counter-narratives" that served as actions of resistance within departments with marginalizing cultures (Secules et al., 2018). The literature examines agency within a broad range of STEM disciplines that have traditionally excluded women and students of color, including engineering, computing, and physics. We have found no studies within the context of geoscience.

For example, Godwin and Potvin (2017) used a longitudinal case study methodology to follow a female high school student who became interested in pursuing engineering during her senior year in high school, because of her experience with an integrated service activity and mentorship from her science teacher. Once she began college, she found herself isolated within her first-year engineering course and eventually left the program. This study found that the opportunities available to students to use background knowledge and to author their science identity significantly affect their ability to develop and leverage their agency.

Gallard Martinez and colleagues (2019) took a different approach by using case studies of two Latina students to examine the process and product of resilience in the STEM pipeline using contextual mitigating factors (CMFs) as a unit of analysis. They defined CMFs as "an infinite set of sociocultural, economical, historical and political contexts which are fluid and dynamic, simultaneously interweaving community, education, family, gender, identity, and other factors" (p. 1081). Similar to ecosystems perspectives, this study recognizes the complex systems that support or hinder student opportunities. Like the braided river analogy (Batchelor et al., 2021), Gallard Martinez and colleagues argue that science educators need to understand the sociocultural factors influencing their students' agency to improve STEM performance.

Ko et al. (2014) used personal narratives and interviews to identify strategies used by women of color in STEM to combat social isolation and unsupportive departmental cultures. This study of 22 women of color with degrees in physics and astronomy, two STEM fields in which national data shows remains "overwhelming White and male" (p. 172) despite encouraging inroads, identified eight forms of agency to persist and advance in their field, referred to as navigational strategies. Hodari et al. (2016) used the narratives of 17 women of color in the computing field to identify additional strategies of agency that were used to persist and succeed. The strategies from these studies informed the ways agency was defined and coded in the current study. Akin to Ko et al. (2014), this study aims to provide models for success and persistence by counteracting the narrative that positions URM students as "passive victims of their environments" (p. 174).

Aim of study

Barton and Tan (2010) argue that when exercising agency, "one's actions within a given field are enabled or constrained by the social structures available there, which themselves are then recreated (or reinforced) by the actions one has taken" (p. 191). The ways students may leverage their agency are restricted (or enabled) by the players in their environment, including policies, faculty, and the departmental and institutional cultures and the roles they are allowed to play (Godwin & Potvin, 2017; Lord et al., 2019; Vaughn, 2020).

In this study, both programs were designed to provide additional opportunities within students' local marine science learning ecosystem to receive research and near-peer mentoring from URM faculty, professionals and students in supportive environments that would prioritize their development. In interviews, students did not share stories about either program's direct influence on their experience or choices; rather they shared examples of how they chose to move within and around those programs to construct the experience that would position them to meet their goals. Researchers identified this as agency, which was then applied *a posteriori* as a construct to the understand the interview data.

Most experiences were an extension of a land-grant HBCU, and thus from an institutional culture that has been less antagonistic than other academic cultures. Exploring agency in this context is a departure from current approaches in the literature. Studies of URM students in STEM typically examine agency in the context of resilience and persistence to adversity and unwelcoming environments, which may be seen as reductionist (Gallard Martinez et al., 2019). We applied themes found within those environments to document whether and how student agency differed when applied to more supportive academic environments and to demonstrate navigational strategies that students used to continue to pursue marine sciences careers (Ko et al., 2014). We refer to this as the marine sciences learning ecosystem, which included undergraduate, Master's and PhD academic programs; a summer internship program; a summer Bridge program; and volunteer opportunities in the marine sciences. Results are interpreted in relation to the braided river ecosystem model to suggest new roles and perspectives that geoscience faculty must prepare to acquire or consider in support of a broad definition of student success.

Setting and study population

This study includes past participants from two marine sciences programs based out of the Department of Biological Sciences at UVI. Both were funded initially through an NSF INCLUDES Design and Development Launch Pilot Project called SEAS Your Tomorrow (Award 1649300) and now have continued support through the NSF INCLUDES SEAS Islands Alliance (Award 1930991). For the purposes of this study, these two programs were considered opportunities in students' marine sciences learning ecosystem.

The first was a six-week, paid undergraduate summer internship program that was part of the Emerging Caribbean Scientists Program (ECS), an umbrella for federally funded undergraduate research programs at the university. Students completed a common application; those selected for SEAS were then matched with local professionals, prioritizing those from the islands and URM communities that work on marine and environmental science territorially relevant issues. Mentors represented a variety of institutions (e.g., non-profits, local government, academia), job types (e.g., research, conservation, education and outreach), and geographies (St. Thomas and St. Croix), to showcase the different types of jobs available in these fields across the USVI. Students interviewed with multiple mentors for positions as both parties needed to agree to the match.

The second program was a Bridge to Ph.D. program that was inspired by the Fisk-Vanderbilt model (Stassun et al., 2010) and that connected students in the Master of Marine and Environmental Science (MMES) program at UVI with faculty and near-peer mentors in the Department of Biology at Pennsylvania State University (PSU) in an eight-week, in-residence paid summer program. Students applied to the program through an application co-developed by faculty at both institutions and were jointly selected to participate in a cohort. All PSU faculty mentors were from URM groups in STEM and were committed to broadening participation and inclusion within marine sciences. The near-peer mentors at PSU were also from URM groups in STEM and demonstrated a commitment to the program's goals of broadening participation.

While at PSU, students participated in a week-long orientation followed by two-week lab rotations with each of the three PSU faculty mentors. Other activities included an outreach activity that supported the local children's science museum and weekly virtual discussions with URM scientists. There were also weekly virtual meetings with the UVI mentors that served as a space for students to voice concerns and for UVI and PSU faculty to make course corrections for the program, if needed. Students were required to prepare an application for a Ph.D. program or equivalent fellowship program in the year following their participation in the program.

If aligned to Figure 1 and the braided river learning ecosystem, both programs stem from a branch of the river that is part of the marine science department at UVI and that might be considered primary branches in the ecosystem. ECS branches from the undergraduate program, while Bridge branches from the master's program. As part of their participation, students navigate transitions from their primary branch to a smaller branch that diverges and then reconnects to the primary branch (similar to that of the REU program depicted in Figure 1). In more recent years, some graduates have transitioned to workforce positions with local agencies and partners. There is overlap in the partners working with the university for ECS and workforce positions, including the Virgin Islands Department of Planning and Natural Resources, Division of Coastal Zone Management; Ocean and Coastal Observing, Virgin Islands; The Nature Conservancy; Virgin Islands Marine Advisory Service; and National Oceanic & Atmospheric Administration.

Table 1. Participant demographics.

	Internship program (N = 7)[1+]	Bridge program (N = 10)
Program Year		
2017	1	3
2018	3	4
2019	3	3
2020	2	NA
Gender		
Binary female	4	6
Binary male	3	4
Race/Ethnicity		
Black	7	4
Hispanic	–	1
Native American	–	1
White	–	4
Native Islander		
Yes	7	3
No	–	7

[1]One student participated in the internship across three years and is included in the totals for 2018-2020.

All students who participated in the internship program from 2017–2020 were invited to participate in the study (N = 11). A total of seven internship alumni completed the interview (64%); one additional alumnus agreed to participate and was never scheduled successfully. One internship alumnus declined participating in the study, and two more did not respond to our requests. Five internship alumni participated in the program the summer after their first or second year (lower division). One internship alumnus participated the summer after their 3rd or 4th year (upper division). One internship interviewee participated multiple years as both a lower and upper division student. Additional upper division internship alumni declined an interview.

Similarly, all Bridge program alumni from 2017–2019 were invited to participate (N = 11). Ten former Bridge participants completed an interview (91%); the final alumnus also agreed to participate and was never scheduled successfully. In recognition of the opposition to the label 'URM' (Williams, 2020), the authors have made a conscious decision to use the moniker as not all study participants identify as racial or ethnic minorities. Some participants were members of other historically underrepresented groups in STEM (i.e., women, low socioeconomic, LGBTQ). Interview participants are described in Table 1. Though some program alumni have now graduated, we refer to all as students for the remainder of the paper.

Methods

Design and data collection

Retrospective interviews were conducted to document students' educational and career journeys guided by a standard protocol. The protocol was not originally intended to gather stories about student agency; instead, agency was identified *a posteriori* as a key construct for understanding students' stories. See supplemental materials for the protocol.

A team of three external researchers conducted the interviews virtually via Zoom during January of 2021. Interviews

lasted between 13 and 70 minutes, with an average of 40 minutes. The number of interview questions varied based on a student's current position. All interviews were recorded and transcribed verbatim with assistance from Otter A.I. Team members conducting the interviews included two Caucasian American females and one African American female. All interviews were conducted by program evaluators with experience evaluating informal STEM initiatives, and all three reside in the Southeastern United States. Two of the researchers currently operate as members of the collective impact Backbone Organization for the current grant funding these initiatives.

Analyses

Students' stories were coded for evidence of student agency as they navigated their marine science learning ecosystem. Navigational strategies, tactics used for coping in STEM environments, identified and defined by Ko et al. (2014) and Hodari et al. (2016) were used as the foundation for the coding scheme and were modified slightly to fit the context of the programs studied (see Table 2 for definitions). The most notable shift was to code the use of agency in relation to both enabling and constraining experiences, rather than only the latter. Data were coded as evidence of a navigational strategy if students took an active role in the story they shared (e.g., made a decision, took action, engaged in some way).

All interviews were independently coded by two researchers using NVivo12. Researchers met periodically for team calibrations throughout the coding. After all the data were coded by each researcher, NVivo files were combined into one document. Researchers then took part in several consensus meetings in which each code was reviewed and verified between the two coders (Hodari et al., 2016); the final dataset consisted of codes that were based on full agreement. Direct quotes are used throughout the manuscript to share alumni stories in their own words. In addition, each interviewer shared the manuscript with their interviewees for member checking and feedback. Each alumnus received an initial invitation to review the manuscript and one reminder across a two-week period. See supplementary documents for the initial email. Two Bridge alumni responded; both were supportive of the framing of interview results.

Results and discussion

The results presented below first describe students and their current positions and then present the ways in which they used agency to navigate the marine science learning ecosystem.

Retention in the marine sciences learning ecosystem

Interviewees participated in either the undergraduate internship program or the Bridge program one to four years prior to their interview. Not surprisingly, students were in different places in their academic and professional journeys at the time of the interview. Importantly, 16 of 17 (94%) were still engaged in the marine sciences, and all were still engaged in a STEM field.

Five internship students were still in the process of completing an undergraduate degree, majoring in either marine biology or engineering. One internship alumnus had just completed their Bachelor's degree and was volunteering in the field of marine biology while applying to graduate school. The final internship student was working toward a master's degree in marine and environmental science.

At the time of their interviews, four Bridge students were enrolled in Ph.D. programs in either biology or oceanography, and all were continuing to study marine science. Two Bridge students were currently Workforce Fellows in the SEAS Islands Alliance program, and another was working as a coral restoration program coordinator at the university. Two additional students were working as scientists for government agencies, both in marine and/or environmental science-related positions. The final Bridge alumnus had completed a master's degree in marine and environmental science and was on the job market looking for positions in the field.

Hecht and Crowley (2020) note that student success is an indicator of a healthy learning ecosystem, and we believe that the results presented here indicate that students have been successful in the continued pursuit of the marine sciences. As demonstrated in the sections that follow, most did not follow a traditional pathway. Some took longer than four years to graduate from college. Others planned for a break in their academic career to earn the income and experience needed to continue their education. Some had already taken a break from the traditional pathway to reassess their commitment to the field and then returned to the marine sciences. Within the braided river analogy, all these choices involve successful navigation of the learning ecosystem.

In the sections that follow, we present the ways that students expressed their agency in pursuit of marine science degrees and careers. Importantly, indirect evidence from our interviews suggests that the learning environments of focus for this study did not include systemic discrimination. Students were asked to describe whether and how they believed their gender, race, ethnicity, socioeconomic status, and/or disability status had affected their academic or professional success to date. None of the students believed these characteristics negatively affected their success; few shared isolated stories about discriminatory behavior, and these examples are described in the sections that follow, but they did not feel these experiences impacted their success or drive to pursue marine science. Students did provide examples of how their identity enabled them to take advantage of unique opportunities such as the internship and Bridge program discussed here.

Here, we present our findings by grouping students' stories in relation to their personal interests in marine sciences, steps students have taken to stay in the marine sciences by

Table 2. Navigational strategy coding scheme and references.

Strategy	Description	Students using strategy	References to strategy
Passion	Referring to their passion for science, including statements about 'being a science person' or having strong skills related to science that guided decision making	15	28
Personal Experience	Applying personal histories, unique experiences and cultural identity to their research and practice	14	37
Confront Challenge	Actively addressing challenges to their merits, comfort or progress	14	32
Environment	Seeking or fostering an environment that enables success	14	25
Soft skills	Developing or using "soft" or non-technical skills to promote their self or eliminate barriers	9	18
Advisor - Positive	Purposely developing a relationship with a supportive advisor	9	14
Get Out to Stay In	Choosing to take a break from STEM academic pursuits (including to gain work experience or for self-care) or transferring to a different STEM discipline	9	10
Peer Network – Positive	Cultivation of supportive peer networks	7	10
Confront Doubt	Consciously counteracting doubt of their abilities within their self or with others	6	10
Activism	Engaging in activism, including the study of invasive species or choices to conduct research in service of conservation or preservation of local ecosystems	3	5
Safe Space	Finding a place where they feel safe to be their whole authentic selves	2	2
Peer Network - Negative	Combating isolation by peer networks	2	2
Advisor - Negative	Circumventing unsupportive advisors	2	2

finding safe spaces and building relationships, and the ways students have expressed agency when confronted with challenges, doubts, and during transitions. For a full list of codes and the frequency with which students shared navigational strategies, see Table 2.

Personal interest in marine sciences

Two codes were used to capture evidence of students' early interest in the marine sciences. The first focused on students' passion for science and the second was based on students' personal and unique experiences.

Almost all students shared their passion for marine sciences as part of the interviews (n = 15, 88%; see Table 2). Prior work related to student agency has found that students remember their passion for science as a strategy to persist in challenging STEM environments (Hodari et al., 2016; Ko et al., 2014). In the contexts studied here, students spoke of how their passion motivated their pursuit of science but not necessarily their persistence in science.

Eighty-eight percent of students shared stories about their passion for science and science-related activities, with some stories dating back to early childhood. Some interview participants talked about the joy of being able to work in a field that they love. Approximately half (53%) of those interviewed shared stories about their interests in STEM and in marine and environmental science topics specifically. Examples from both internship and Bridge students included these:

> *My passion and my love for marine biology. I think that's what [friends and family] would say…Whenever I talk about marine biology, they say a smile is always on my face, and how I am always talking about sea turtles. I can go for hours talking about it. All about conservation, theory of evolution… I think most would say my passion for marine biology made me a successful science student. — Upper Division Internship alumnus*

> *It's very frustrating work at times, but it's very rewarding. I was seeing some of my other friends in their careers. I just feel like I'm really fortunate because I have, like I get to really follow my passion. Whereas some of them feel like they're doing more of the grind. I think that's a big part of it. I feel like science is kind of fun because you are just still that kid who gets to ask cool questions and you get to go work in the water. It's a fun field. It just keeps you stimulated. — Bridge alumnus*

Students also shared stories about how their personal histories and research experiences influenced the actions they took to pursue marine science. Most students (83%) shared experiences that were coded to this category; this code was the most prevalently used across the entire coding scheme. Hodari et al. (2016) found that their participants' personal histories and unique experiences influenced how they approached their research and what they studied, such that their research was personal and aligned with other aspects of their identity. In the context of our programs, personal experiences were attributed, instead, to stories of persistence. Forty-one percent of students shared personal and unique experiences that they believed influenced their thinking about future careers. For some, these experiences supported their research interests, helped identify career options, or confirmed that they were on the right path. For others, these experiences exposed them to new things and helped them make connections in their research. One student shared:

> *I was working with [my mentors] to make a program about the way the sun was giving off solar energy…I was like "Wow! I can actually do this…if I want to go try and get into this, it's actually possible" … And both of them just showed me that you just have to kind of put your feet in there and get your feet wet to actually make the connection…And it's not as hard as you would think. — Lower Division Internship alumnus*

Students also shared how their preferred activities and personal histories influenced their success as a science student. They often shared ways that they had benefited from

their status as an underrepresented or nontraditional student, as exemplified by the following:

> *My background and being a minority has very much helped me. First of all, just by being a part of the SEAS Alliance program… it is, you know, targeted at minorities to help them… the big scholarship that I got, a scholarship/internship. But again, in the name it is specifically for students who attend minority serving institutions. And because I am attending UVI, which is an HBCU, it has been extremely, extremely helpful being able to have gotten that scholarship. — Lower Division Internship alumnus*

Staying in by finding safe spaces

Prior work has found that students' express agency by identifying academic or professional cultures that are known to be understanding or supportive of those from typically underrepresented groups (Hodari et al., 2016; Ko et al., 2014). The results from our interviews indicate that both the university and its related programs provided supportive environments; 83% of students shared stories of how their environment enabled their success. Students expressed agency within that environment by exposing themselves to new experiences (29%), seeking specific opportunities to prepare them for their future (24%), preparing themselves for success by developing new skills (18%), participating in programs outside their home department (18%), actively participating in groups or targeted events (12%), and by cultivating relationships (12%).

Students who sought specific opportunities did so to address gaps in their experience or knowledge. Some shared how their experiences with supportive activities prepared them to take next steps in their journey. These stories included the following:

> *I feel like my participation in the program has set me up to be where I am today…I am really grateful for the opportunities that the program has presented to me, which allowed me to feel comfortable staying here at UVI to continue for a master's program. They've supported me financially, emotionally. Yeah, in a lot of different ways. — Lower Division Internship alumnus*

> *I did the Bridge program to Penn State…Honestly, I didn't really get a lot of guidance on how to transition into [my] master's program so I think that was really a big thing for me, that transition into a Ph.D.…So that now, later on, I'll know how to make that transition. — Bridge alumnus*

Prior work has demonstrated that students use their agency to navigate negative academic environments by using "soft skills" to address potential barriers (Hodari et al., 2016). Just over half of the students in our study (53%) mentioned these skills when describing their educational and career trajectories. Comments focused on developing communication and networking skills. In addition, two students mentioned time management and one noted critical thinking as skills they had actively developed over time. The range of "soft skills" that students have applied included the following:

> *I even ended up making a YouTube channel and started vlogging and everything. I mean really and truly everything I do is surrounding marine biology. — Lower Division Internship alumnus*

> *In my first internship, when I was working with [my internship supervisor] she brought us a big calendar…and she made us go and actually do a detailed list of what we're going to be doing day by day. And that's really has become something that I've now taken with me, with every internship I do, and with even outside of internships. — Lower and Upper Division Internship alumnus*

Recall that the results presented earlier confirm that most students did not feel negatively affected by their URM status at the university or as part of either program. Even so, two students made specific references to the need to find a 'safe space'. One student reflected on past experiences doing robotics, and how they were often the only Black person in the room. That experience changed at UVI, which they found "comforting." The other was a local student who had recently begun a graduate program where they were amongst the minority. They referenced weekly meetings with SEAS mentors that have served as a safe space to share experiences and receive support.

Staying in by forming relationships

Students shared examples of exercising agency in seeking out mentors and advisors, and in the ways peer groups offered support to one another. Stories in each category were coded in relation to both supportive and discouraging experiences. Researchers found that most of the stories shared about advisors and peer networks were reminiscent of encouragement and support.

Fifty-three percent of students reported actively pursuing a relationship with an advisor they hoped would be encouraging and supportive in their academic and occupational journeys. Twenty-four percent reported actively reaching out to current and potential mentors with hopes of developing relationships or in pursuit of opportunities. Twenty-four percent also told stories of advisors who shared their social capital by using their privilege and influence to provide opportunities or to help students make connections with colleagues. In each story shared, students hinted at a trusting relationship with their advisor that was created over time and focused on ensuring that students were able to get the experience needed for their future pursuits. For example, one student shared:

> *I would say I formed a really good professional relationship with one of the mentors in the Bridge program. She's a really strong mentor and a really great educator. I think that further solidified me wanting to be some type of mentor or educator, especially in my community. — Bridge alumnus*

Two students shared stories in which they had to circumvent unsupportive or hostile relationships as part of their academic journeys. One shared that they had to find a new lab assignment because their supervising faculty member held and vocalized sexist beliefs. The other shared a hostile working relationship that was created because they needed to work rather than supporting their

advisor's lab full-time. In both situations, the students used their agency to change the situation. The first was able to transfer to a lab with a more hospitable working environment. The other did not give in to their advisor's pressure. Both instances reveal that, although HBCUs typically employ people who are supportive of marginalized groups, they are not completely void of the colonial values ingrained within academia. As demonstrated here, values such as a sense of urgency, the belief that there is one right way to do things, fear of conflict, and paternalism can still be found (McGee, 2020; Okun, 2021).

The results in this section thus far have mainly focused on faculty relationships. Some students also shared stories about their experiences with positive, supportive peer groups. Twenty-four percent noted choices they have made in creating and supporting their peer network. Examples included:

> *The friends that I surrounded myself with and the classmates I find myself with, they kind of motivate me to keep going. A lot of my classmates are in my same major. We all have that same, 'It has to get done' kind of attitude. It's very motivating, especially when we have an assignment. — Lower Division Internship alumnus*

Two students reported having experienced unsupportive peer networks with their classmates. One program alumnus experienced isolation within her graduate school cohort. The other felt that their Bridge program cohort members were unsupportive and discouraging to the point that the student reported experiencing imposter syndrome.

Finally, students shared examples of expressing agency to give back in a variety of ways. Ko et al. (2014) defined activism as volunteering in STEM related fields or areas. Here, activism was defined more broadly to include research and other activities that aim to better society; a total of three students shared stories in this category (18%). All three shared ways that they provide outreach and support to younger students. One shared connection between the science they conduct and environmental activism. Examples of these types of relationships and experiences included these:

> *I volunteer with the coral relief strike team doing dives…to go out to see how they are doing and figuring out which reefs need aid and which don't. I don't know if you know, but a lot of [reefs] do. Now it's just time to help with the treatments and everything. — Lower Division Internship alumnus.*

> *This is something that I believe happens to a lot of Black people or people of color, or just any marginalized community…There is an expectation that as a [person of color], I need to succeed. I need to be able to accomplish a couple things. And then I need to turn around and mentor other students, if we're going to increase more minorities and Black people or people of color into these fields. And so that's definitely been something that I think is expected of me due to my race… — Bridge alumnus*

Confronting challenges and doubts

Most students also shared stories about confronting challenges as they navigated their marine sciences learning ecosystem. Eighty-three percent of students shared stories about confronting some sort of obstacle to their success. Some shared stories of having to overcome their own academic performance issues. For several people, the challenges of low grades were the result of or confounded by economic hardships and responsibilities. Even when economic and social responsibilities did not result in poor grades, these challenges affected students' ability to meet other departmental obligations and expectations or gain experience that would further their career objectives. One such story follows:

> *I had to spend a lot of my undergrad years working. I couldn't fully afford college myself. Because I was always working, I didn't always get the best grades. Then that became a bigger problem for me as I was going, "Okay I want to do a Ph.D." But I was always told by many advisors, I would never make it because I don't have like a 3.5 or 4.0 GPA… Then I devised the plan, I'll do a masters… I can improve my grades in my master's program and be better. I did improve my grades… even though I had a scholarship, I still had to work. I can't afford to be a student that just focuses on school because I'm always working.* — Bridge alumnus

Some students (18%) experienced challenges in the form of expectations within the field, specifically academia. One Bridge alumnus shared how they chose to advocate for themselves and others around expected deliverables from the program:

> *They laid out all the requirements at the beginning of the program, and I did not want to apply to a Ph.D. I thought it was kind of frustrating that they would lay that out as a requirement, because I thought the whole point of the program when we had started was to get experiences like a Ph.D. student and to see if that's what you want to do. If you decide that maybe a Ph.D. is not for you, you shouldn't be forced to apply for a Ph.D. program…. After pushing back on it we just settled for just applying to something. — Bridge alumnus*

During the meetings to compare coded data, the authors noted that the differences between data coded as Confronting Challenges and those coded as Confronting Doubts were minor, with many data points having the potential to be coded with either theme. Analysis found that all six students (35%) who shared stories of confronting self-doubt also shared stories about confronting various challenges. Students who doubted their abilities often shared stories related to cultural norms in academia and STEM departments that typically focus on the "best and brightest" (McGee, 2020). A student shared:

> *I think one of the things I've become more aware of is that I'm very conscious of where I am within my field and science. I'm not necessarily the most intelligent of the people in the group. I have to work a little bit harder to understand concepts…But I think in that process I've learned how to grind harder, since I'm not maybe as academically gifted as I feel some of my colleagues are. I think that has been a challenge. — Bridge alumnus*

Two program participants reported challenges related to their identification as a URM student. The engineering student who was also interested in marine biology reported

feeling isolated at times but used it as his motivation to inspire other Black students. Another alumnus shared the following story:

> *I had a science lab, and I had just spent the summer looking at corals, all summer. And I was trying to explain to my partner that this is how we're supposed to do it because of this, this, and this. And I explained to him, I had to go through this list of why you should listen to me, because I did this program. It was kind of annoying because then…a teacher who was also a guy came and said, 'No, she's right.' And he was like, 'Oh, I didn't think she was right.' Why would I lie? — Lower Division Internship alumnus*

About half of the students (53%) talked about being able to remain in the geosciences by switching disciplines or taking a break from school. Twenty-nine percent shared stories about reaffirming or switching to a new STEM major. Many times, the switch or decision not to switch was related to perceived workload in combining multiple STEM interests, for example marine science and engineering or biochemistry, or finding the right program to meet their personal goals. One Bridge student shared the following from her undergraduate experience:

> *I knew I wanted to go there because I knew they had a good Marine Science program. I transferred in my sophomore year and I transferred in as a Biology major because I had always just kind of had that idea of, you know, marine biology, I have to go the biology route… the biology program there was a lot of pre-med students and it just, it wasn't really sitting right with what I wanted to do. Through a friend's recommendation [I] took an environmental science class with the professor she liked… it was just so much more aligned with what I wanted to be studying. — Bridge alumnus*

Eighteen percent of students mentioned taking a break from academia to join the workforce. Some students decided to take a break because of financial demands. The range of students' decisions related to "getting out to stay in" included the following:

> *Out of college I said, "I'm gonna take a break from science, and basically see if I miss it." And it was pretty much unanimous…I couldn't wait once I had the opportunity to pursue my master's down here. I couldn't wait to do that, to start that to get back into research. And so yeah, I wanted to take a break, it was very, very brief and only confirmed what I felt before. — Bridge alumnus*

> *So, right now while I'm working with [a Federal Agency]. Basically, my intention here is to just work here for a while—save some money, make some money—and while doing so, work on publishing my thesis, so I can have a better foot in the door when I decide to apply for Ph.D. programs. — Bridge alumnus*

It is important to note that none of the instances of "getting out to stay in" were in response to departmental culture, as reported in other studies (Ko et al., 2014). Similarly, in contrast to previous studies, students did not speak about finding ways to escape from the demands of a STEM degree or career. At the time of these interviews, none of the students shared concerns about the expectations placed on scientists and how to achieve work-life balance. This early sign of success may be particularly noteworthy given the wide range of choices and educational and career positions being held currently by students (e.g., continuing from undergrad to pursue a master's degree; continuing from a master's degree to pursue a PhD; choosing to work for a government agency rather than pursuing a PhD).

Implications

We have applied the construct of student agency to understand how students navigated their journey through the marine sciences learning ecosystem. The results included those from students who were still completing their undergraduate degree, those applying to and attending graduate programs, and those who were now part of the marine sciences workforce. In many ways, students' stories included the use of agency we would hope to see for all students. Their passion motivated their pursuit of science, their personal histories and research experiences influenced the actions they took to pursue the geosciences, and they worked with mentors and peers to identify new experiences and specific opportunities to prepare them for their future. What was different was that these were URM students who traditionally are not provided a space to see themselves succeed in STEM fields, and the geosciences in particular, who were able to continue, leave and reenter the marine science learning ecosystem on their own terms without questioning or defending *if* they belonged while being able to self-determine *where* and *how* they belonged. We believe that students' stories highlight some of the ways multiple pathways to success may be encouraged by implanting spaces and places within the learning ecosystem where students can feel supported and engage in ways that affirm their personal journey and choices.

Agency looks different in enabling environments

In their call to action, Hecht and Crowley (2020) suggest studying the transitional boundary zones in a learning ecosystem as an indicator of a healthy system. At a minimum, SEAS students transitioned from their degree program to their summer research program and back again. For example, most Bridge alumni in this study have transitioned to the next stage in their education to pursue a PhD or entered the workforce. Participants also shared choices they navigated before entering the SEAS programs and in the years following their involvement. Given the fact that almost all students were still involved in marine sciences, we believe the SEAS programs operate as transitional boundary zones within a healthy learning ecosystem. We believe that other institutions can nurture their learning ecosystem by fostering and supporting these boundary zones, particularly through the creation of interinstitutional partnerships and safe spaces (sometimes called counterspaces) that provide opportunities for students to meaningfully engage with near-peer and faculty mentors in ways that affirm students', and URM students in particular, journey and sense of belonging.

Interinstitutional partnerships, such as those created for both programs, may help mitigate traditional barriers and training silos while also addressing curricular misalignment between the undergraduate and graduate stages, especially for those students at MSIs that may lack access to graduate programs and faculty (Allen-Ramdial & Campbell, 2014). Successful partnerships, such as the Bridge program, should involve key decision-makers from both institutions in program design and oversight, emphasize students' potential instead of their proven ability, and prioritize the development of mentoring relationships between participants and faculty so that they can become persuasive advocates and brokers for the students (Karstein, 2019; Stassun et al., 2010). A strength of the current partnership was that it was initiated and informed by educators from the HBCU in collaboration with URM educators from the R1 institution with similar commitment to creating inclusive marine science experiences. The results from this study suggest that successful partnerships between HBCUs and PWIs have the potential to provide experiences that are often not available through HBCUs (Karstein, 2019; McDaris et al., 2017) due to lack of equitable funding structures (McGee, 2020) while providing the PWI with opportunities to recruit and retain URM scholars and learn effective strategies for broadening participation (Núñez et al., 2020).

Both programs may have functioned as counterspaces for students. STEM counterspaces are "safe spaces" for marginalized or nontraditional groups that typically lie outside of mainstream educational spaces and are created in response to issues of access and equity, such as isolation and microaggressions (Ong et al., 2018). Ong et al. (2018) found that almost all the women of color in their study sought out or created counterspaces through peer-to-peer relationships, mentoring relationships, participation in national STEM diversity conferences, as well as STEM and non-STEM affinity groups. They also found instances of STEM departments functioning as counterspaces.

When departments serve as counterspaces, they find ways to dismantle barriers and disrupt patterns of privilege and marginalization within existing academic cultures. This allows the focus of broadening participation to move from the individual to the institutional while transforming the perception of diversity from an issue to be addressed to a foundational component for scientific excellence (Karstein, 2019). Ong et al. (2018) identified a range of ways in which the "center can become the margin" and that we believe are evidenced in the design of these programs. For example, the cohort structure of both programs simulated a *critical mass experience* where students could foster a sense of social belonging, feel supported and are less likely to be subjected to microaggressions and feel obliged to perform to "prove themselves" worthy. Similarly, near-peer relationships and mentorship fostered programmatic *cultures that were supportive and collaborative*. Students also had a chance to engage and expand their place-based knowledge by participating in research projects that were responsive to the current needs of the USVI, thus *valuing and embracing the cultural knowledge* of Islanders.

Gonsalves and Chestnutt (2020) found that departments could create counterspaces that supported students' reconfiguration of the characteristics of the "model scientist" by positioning brokers [faculty and administrators] who could disrupt the department and university hierarchies and form significant relationships with students. Brokering is an important part of any learning ecosystem by dismantling silos and networks that have traditionally excluded URM students and providing access to opportunities that will help them achieve their goals (Akiva et al., 2017; Allen et al., 2020; Ching et al., 2016; Penuel et al., 2016). The structure of both the internship and Bridge programs allowed program coordinators and mentors to spend time with students to develop relationships and broker opportunities that would contribute to students' success. For example, three out of the four Bridge alumni identified and connected with their Ph.D. advisor through the program.

The intentional design and study of counterspaces has interesting implications for changing departmental culture and supporting students to achieve their desired educational outcomes. Working together through an intentional design process might foreground and apply the science that supports culture change within departments and with a wider swath of faculty than those who might read this literature on their own. The study of such processes and systems, and department-level consideration of the resulting data, might also add a layer of accountability that will be meaningful for some faculty. Studying these types of processes and relationships is another example of applying ecological approaches to education research.

These types of relationships and success stories — that include the role of caring, knowledgeable, and connected educators — have the potential to impact the health of the larger ecosystem (Hecht & Crowley, 2020). This role can be considered an extension to that of change agent in the geoscience education literature (Macdonald et al., 2019; Posselt et al., 2019). The results of this study reinforce the importance of educators as both designers of and mentors in a marine science learning ecosystem. Several student stories mentioned the specific and nuanced ways that mentors supported students' opportunities and development. Mentors also shared their social capital to provide opportunities and support networking (Martinez-Cola, 2020; Figueroa & Rodriguez, 2015). The broader perspective of success established through the braided river analogy provides additional nuance to how change agents can be defined and offers additional opportunities to integrate multicontext theory beyond the curricular strategies suggested by Weissmann et al. (2019) as the geosciences strive to create a more inclusive academic culture.

Though the results presented in this study are promising, they also include hints of disturbing patterns that have been reported extensively elsewhere about Black students who prioritize success over their mental and physical health (McGee, 2020). Students described learning to "grind harder" and shared examples of additional expectations placed on them that are based on being a URM in geoscience. Others noted a lack of tolerance for financial situations that required students to hold additional jobs

rather than devoting all their time to the lab. These expectations and challenges require changes within the learning ecosystem to dismantle the narrow perceptions of success for students and faculty alike.

Limitations

Though we are encouraged by the stories of how students used agency in the context of the marine sciences learning ecosystem studied, we also recognize the need to interpret our results with caution. The sample size for this study, while inclusive of most students, is small and may be biased toward successful navigation of the pathway. Students were also at different stages in personal development, as well as their collegiate and professional careers at the time of their participation in the program and their interview with researchers.

While the results presented here do demonstrate the utility of using agency as a construct to study how students navigate a learning ecosystem, these data were not collected with a priori plans to study agency. The story-based questions included in our interview protocol, and the questions about specific times in a student's life may have influenced the types of agency-based stories students shared. The evidence reported from our sample is likely to present an initial rather than comprehensive understanding of the utility of this construct in understanding how students navigate a learning ecosystem.

Conclusions

In their recent review of geoscience education research, Mattheis et al. (2019) note the importance of changing the shared social practices utilized within the geosciences to support inclusion, and particularly regarding how success is defined. It is our hope that the results shared here provide additional considerations for those interested in changing the culture of geoscience through targeted and responsive opportunities to create healthy learning ecosystems.

We believe that the programs created through SEAS are examples of approaches to improving a learning ecosystem (Hecht & Crowley, 2020) that can be used by others to foster similar inclusive practices at their institutions. We also believe our results provide initial evidence to support a role for the construct of student agency as an area for further study and as an enabling concept that faculty should consider and support. The prevailing meritocracy in academia limits the choices and perspectives available to students and faculty alike, perpetuating ideas about pipeline and pathway trajectories that are neither realistic nor inclusive (Batchelor et al., 2021; Mattheis et al., 2019). Ecosystem models in general, and the braided river analogy in particular, support varied, individualized pathways to success. Batchelor et al. (2021) argue that academic departments need to prepare to support and celebrate these successes. The SEAS programs and faculty serve as models for supporting students as they navigate the opportunities available in their learning ecosystem. We believe the fact that almost all students are still engaged in marine sciences to be a testament to the importance of this broader perspective, and that continued study of student agency within these types of enabling environments can provide valuable information for the field as it strives to become more inclusive.

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