K-12 Diversity Pathway Programs in the E-STEM Fields: A Review of Existing Programs and Summary of Perceived Unmet Needs

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Introduction

Statement of Problem— The number of available jobs in environment, science, technology, engineering, and math (E-STEM) is growing rapidly. Employment in STEM fields grew 24.4% between 2007 and 2017, as compared to 4.0% growth in other occupations (Noonan, 2017a). STEM occupations are expected to increase by 8.9% between 2014 and 2024, with Environmental jobs expected to increase by 11% (BLS 2018), versus a 6.4% increase for occupations outside of the STEM fields (Noonan, 2017a).

As the E-STEM fields grow, women and Latinx, Black, and Indigenous people remain underrepresented in E-STEM professions. While women make up roughly half of the population of the United States, they hold only 24% of jobs in STEM (Noonan, 2017b). Latinx individuals make up 16% of the workforce in the United States, but only 6% of individuals employed in science and engineering positions (NSF, 2017). Black individuals make up 12% of the population, but only 5% of the science and engineering workforce (NSF, 2017). American Indian and Alaska Native individuals are likewise underrepresented in the science and engineering workforce (NSF, 2017). Latinx and Black individuals are also under-represented among environmental NGO staff and boards (Taylor, 2018). There are a multitude of interacting factors that influence this lack of representation, including overt discrimination, implicit biases, socialization, and a lack of role models in the E-STEM professions (Ceci, 2009; Ong, 2011; Poirier, 2009).

The increasing demand for qualified E-STEM professionals provides potential to shift representation of women and racial and ethnic minorities in these fields to be more consistent with the United States population. Research indicates that demographically diverse groups are more likely to be cognitively diverse, and that cognitively diverse groups are more innovative than homogeneous groups (van der Vegt, 2003). Women and Latinx, Black, and Indigenous people represent a significant body of untapped talent with the potential to positively influence innovation in the E-STEM workforce.

Summary of the Literature—The pathway through the education system and into E-STEM professions has been described as a "pipeline," where the barriers to attracting and maintaining individuals or groups of individuals in E-STEM are characterized as "leaks" in the pipeline. Other authorities prefer the term "pathway" to "pipeline," to indicate that movement into E- STEM fields isn't a "one size fits all approach" and to account for the heterogeneity of students (Altman et al., 2008). A number of pathway/ pipeline programs have been established with the goal of attracting and retaining individuals from underrepresented groups in various professions.

Several reviews have aimed to summarize K-12 diversity pathway and pipeline (hereafter pathway) programs, particularly in law and STEM fields. A report from the Access Group Center for Research and Policy Analysis (2015) summarizes the need for pathway programs, beginning at the elementary level and continuing through later years, to enhance racial and ethnic diversity in the legal profession. It analyzes 261 pathway programs for the legal profession in the United States, outlining their target population, grade level, and the services they provide (ex. bar passage program, mentoring, student-oriented class, internship, etc.). The article reports best practices for pathway programs in the legal profession and proves recommendations for program leaders and supporters. However, this study does not explore the relationships between services provided and demographic targeted, nor does it analyze the relationship between the types of programs offered and the age level targeted.

Additionally, Bayer Corporation (2010, 2016) summarized several STEM pathway programs that meet particular criteria, such as having a challenging curriculum, using inquiry-based learning, collecting outcomes using assessment tools, and procuring community support. For each program, Bayer Corporation (2010, 2016) provides a description of the target population, community partners, learning environment, and program outcomes. Similarly, Jeffers et al. (2004) outlines several K-12 STEM pipeline programs and identifies common themes among those programs. Though these studies outline several programs, they do not comprehensively review and analyze K-12 E-STEM pathway programs and their various programmatic components.

Other studies have focused narrowly on pathway programs for the health professions (Patterson, 2006), undergraduate women in science and engineering (Fox, 2009), increasing minority and disadvantaged student enrollment at undergraduate institutions (LaGuardia, 1998), or on the role of undergraduate enrichment programs on graduate school matriculation in STEM (Merolla, 2013). To our knowledge, until now, there has not been a comprehensive literature review of K-12 programs geared toward participants from underrepresented backgrounds that summarizes the location of these programs, the targeted age groups and demographics, and the discipline-specific pedagogical methods these programs use.

There is a specific need for pathway programs in environmental sciences that may not be addressed by programs designed to broadly target leaks in the STEM pipeline. Of the 40 largest environmental non-governmental organizations, only 27% of full-time staff were people of color ("Green 2.0," 2017). Studies on the characteristics of STEM pathway programs may not explicitly "integrate environmental education into STEM learning" and may instead focus on biology and chemistry as the core sciences ("NAEE," 2018).

Because there has not been a comprehensive review of the characteristics and goals of K-12 E-STEM pathway programs in the United States, we aimed to study important aspects of existing programs to identify unmet needs, including gaps in discipline or target audience. It is also important to understand the breadth of programs offered, the methods of recruitment, and programmatic outcomes. Additionally, there are unknowns about the objectives of K-12 E-STEM pathway programs, the demographic targeted, and whether there is a relationship between the two. We also wanted to understand the grade levels that these programs target and the pedagogical methods used in these programs.

This study contributes to our understanding of what educators, programs, and partners can do to address the gaps in the E-STEM pipeline programs offered. This information is critical to helping develop programs that successfully facilitate students navigating their own path to careers in E-STEM.

Study Context– Duke University's Nicholas School of the Environment has recently launched a comprehensive strategic plan for K-12 pathway programs in the environment. Currently, the Nicholas School of the Environment supports three K-12 diversity programs in E-STEM, including the Environmental Science Summer Program (10-12th graders, city-wide); Girls on outdoor Adventure for Leadership & Science (GALS, 9-12th grade girls, state-wide), and the Duke University Marine Lab Community Science Initiative (rural communities and students).

As we continue to develop programs (e.g., Durham Public Schools and Nicholas School of the Environment mentorship program) and refine our strategic planning, we sought to gain a deeper understanding of the goals, practices, and methods used by E-STEM programs. As women in STEM fields, we wanted to learn more about existing programs and understand why some fields, groups, and techniques might be over- or underrepresented in these programs. Given this background, we explored the following questions driving questions: 1) What are the characteristics of E-STEM programs that exist for students from underrepresented backgrounds? 2) What are the techniques used to prepare students for the next stage in the E-STEM pathway?

We have structured our manuscript as follows. We explain our methodology and conduct a thorough literature review to uncover trends in the E-STEM literature in K-12 contexts. We then summarize this literature, supplementing summaries with Chi-square analyses. We conclude with a discussion of these results and implications for future research.

Methods

Article Collection Process— To answer these questions, we conducted a literature review. We collected peer-reviewed journal articles from the following databases: Education Full Text, Environment Complete, ERIC, PubMed, ProQuest Science Journals, and Web of Science. We searched Education Full Text, Environment Complete, ERIC, and PubMed databases through EBSCOhost. We searched ProQuest and Web of Science independently through the database websites. We chose databases with a focus on education and pedagogy (Education Full Text, ERIC), with articles in a wide range of E-STEM fields (ProQuest Science Journals, Web of Science), or with a specialization in a particular E-STEM discipline (Environment Complete, PubMed). These databases allowed us to identify a broad scope of literature describing educational pipeline programs, including in E-STEM fields.

We queried the databases using nine search phrases, yielding an initial total of 4996 articles. The preliminary criteria for article selection was that the article must describe a diversity pathway program, defined as a program for K-12, college, or teacher education aimed at increasing the demographic representation in a particular field. We eliminated 4799 articles that did not embody our definition of diversity pathway program or that were redundant between search databases, resulting in 197 applicable and unique articles (Fig. 1).

Search phrase	# Articles from ProQuest	# Articles from Web of Science	# Articles from EBSCOhost databases (other)
pipeline AND program AND K-12	34	30	118
diversity AND program AND K-12	1523	67	180
pipeline AND K-12	415	63	180
minority AND program AND K-12	776	69	180
minority AND pipeline AND K-12	160	5	64
"education pipeline" AND diversity AND K-12	6	0	11
diversity AND pathway AND K-12	769	54	42
minority AND pathway AND K-12	196	6	46
"education pathway" AND diversity AND K-12	2	0	0

Figure 1. ProQuest, Web of Science, and EBSCOhost results by keywords with non-target articles elimi nated, paring results from 4996 to 197 articles.

Coding Process— The 197 selected articles were coded into nodes and sub-nodes using NVivo Version 11.4.2. Coding was divided between two individuals, who coded all 197 articles for half of the following nodes: discipline-specific techniques, grade level, institution type, location, mentoring, and pipeline preparation, discipline, demographic targeted, evaluation techniques, objectives, recruitment techniques, and statistics (Fig. 2).

Results

Overall Findings— Of the pipeline programs described in the 197 articles coded, 148 fell into distinct disciplinary categories. The greatest number of programs was in environmental science and the geosciences (24%), followed by engineering (21%), science (16%), technology (14%), math (11%), health (6%), and the social sciences (5%). Most programs from our literature search were located in the United States (95%), with the plurality being in the Southeast (26%) followed by the Northeast (22%), Midwest (19%), Southwest (11%), Northwest (6%), Alaska (1%), and Hawaii (0%). Several programs had branches in multiple locations across the United States (10%) and some were located outside the United States (5%).

Most programs were hosted by institutions of higher education (51%), though others were federal programs, partnerships between school districts and universities, multi-institute partnerships, non-profit programs, school-based programs, or were hosted by professional societies. Of programs that described a specific strategy to prepare students for the next stage in the pipeline, the most common strategy was career advising (47%), college counseling (32%), or preparation for the next grade level (21%). The most frequent program objective cited was developing interest (29%), followed by enhancing diversity (21%), providing opportunities (16%), teaching skills (11%), improving education (10%), access (6%), retention (5%), and improving self-efficacy (3%). For recruitment techniques, university and company partnerships were the most popular (47%). In the classroom techniques (27%), outreach programs (24%), and enrollment tracking (1%) were not as frequently cited.

Age Group— Overall, a greater number of programs target high school and middle school aged students than elementary school students. Of articles that reported their targeted age group, 33% were general K-12 programs, 37% were high school programs, 23% were middle school programs, and 6% were elementary school programs.

We calculated a Chi-square test of independence to evaluate whether the age group targeted by a given pipeline program was independent of the pipeline program's discipline. A significant interaction was found ($X^2(18)=32$, $p<0.05$). The lack of programs for elementary school students is particularly notable in environmental science programs. Of environmental science articles that reported their targeted age group, 50% were K-12 programs, 33% were high school programs, and 0% were middle school or elementary school programs.

When we combine environmental and geoscience programs, of those articles that reported the program's targeted age group, K-12 programs made up 46%, high school programs made up 46%, middle school programs made up 8%, and elementary school programs made up 0% (Table 1).

Driving Question	Main Nodes	Sub-Nodes
Where is the program located?	Location	Alaska Hawaii Midwest U.S. NE U.S. NW U.S. Outside U.S. SE U.S. SW U.S. Territory U.S. (multiple locations)
What type of institution is hosting the program?	Institution Type	Federal, NSF, NASA Institution of higher education Multi-institute partnership (more than 2 collaborators) Non-profit Professional society Public school district School (not public) University/school district partnership
What are the primary objectives of K-12 diversity pipeline programs?	Objectives	Access Develop interest Enhance diversity Improve education Improve self-efficacy Provide opportunities Retention Teach skills
What demographics are targeted by K-12 diversity pipeline programs?	Demographic Targeted	Black students Indigenous peoples Latinx Location Socioeconomic status Underrepresented minorities Women
What techniques are used to recruit participants?	Recruitment Techniques	Enrollment tracking In the classroom Outreach programs University and company partnerships
What techniques are used to teach participants disciplinary content?	Discipline	Engineering Environment Geosciences Health Mathematics Science Social Sciences Technology
	Discipline-Specific Techniques	Active learning (specific phrase used) Coding (specific phrase used, or article discussed use of a computer programming language) Field work (research in clinical or outdoor setting) Hands-on learning (specific phrase used, or article discussed construction/manipulation) Informative presentations (i.e. lecture or guest speaker) Inquiry (specific phrase used, or Lab experiments Place-based learning Readings Student presentations Technology-based learning
What techniques are used to prepare students for the next stage in the pipeline?	Grade-Level	K, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 K-12 Elementary Middle High College Teachers
	Pipeline Preparation	College counseling Career advising Preparation for next grade level
How are programs evaluating success?	Evaluation Techniques	Embedded assessment Outside feedback Participant feedback Post-survey Pre-survey Qualitative methods School data Student attitude surveys
What data-driven, statistically supported evidence exists to support the use of techniques meant to recruit participants, teach disciplinary content, or prepare students for the next stage in the pipeline?	Statistics	Demographic targeted Objectives Retention
	Mentoring (specific phrase used, peer or adult/professor/career mentor	N/A

Figure 2. Nodes and sub-nodes used to code articles Statistics— Chi-square analyses were conducted to identify trends and relationships among the nodes and sub-nodes. Often relationships were compared among disciplines.

Discipline-Specific Technique— A Chi-square test of independence was conducted to determine whether the discipline-specific techniques used in a given pipeline program was independent of the pipeline program's discipline. Overall, discipline-specific technique was not significantly related to discipline ($X^2(60)=65$, $p>0.05$). Inquiry and hands-on learning techniques were the most frequently referenced discipline-specific techniques in the study. Of all articles in the literature search, 44% referenced inquiry as a component of a K-12 pipeline program, and 40% referenced hands-on learning. The next greatest representation of a discipline-specific technique was informative presentations (26%). All disciplines other than health and technology had inquiry as their highest represented technique; health had hands-on learning as its highest represented technique, and technology tied for inquiry and hands-on learning as its highest represented techniques. Of all articles that were coded into a discipline, 61% referred to inquiry and 53% referred to hands-on learning. The next greatest technique referred to in articles that were coded into a discipline was informative presentations (38%).

The discipline that most frequently referred to inquiry was environmental science; 100% of environmental science articles referred to inquiry-based learning. Combining environmental and geoscience articles, 69% of those articles referred to inquiry-based learning.

Of the discipline-specific techniques studied, the frequency with which articles referred to coding is the lowest, even in engineering (19% of articles) and technology (14%). Of all articles that were categorized into a discipline, only 5% referred to coding as a program component (Table 2).

Demographic Targeted— Of the demographics targeted, "underrepresented minorities" are overwhelmingly the majority (48%). The caveat with this statistic is that "underrepresented minorities" encompasses the other diversity sub-nodes we coded, so the participant demographics of programs that targeted "underrepresented minorities" might be more nuanced. Socioeconomic status and women are the second most represented diversities targeted, both at 13%. Next is Latinx students (8%), followed by Black and Indigenous peoples (both at 7%), and then Location (4%) (Table 3). Technology and the environment and geosciences targeted Indigenous peoples (19% and 14%, respectively) more than other E-STEM disciplines. However, at least one program in each discipline, except for the social sciences, had a program geared toward Indigenous peoples. Chi square analysis ($X^2(36)=39$, $p>0.05$, $p=0.349$) does not indicate that there is a significant relationship between discipline and demographic targeted.

Objectives— "Developing interest" and "enhancing diversity" were the most frequently cited program

	Engineering	Environment & Geosciences	Health	Math	Science	Social Sciences	Technology
K-12	7	12	1	2	3	1	8
Elementary	0	0	1	0	0	0	0
Middle	8	2	2	5	5	1	1
High	8	12	4	1	4	0	2

Table 1. Number of articles citing pipeline programs that target various age groups, organized by program discipline.

	Engineering	Environment & Geosciences	Health	Math	Science	Social Sciences	Technology
Active learning	8	16	3	2	3	1	7
Coding	6	1	0	1	0	0	3
Field work	1	14	2	1	2	2	1
Hands-on learning	18	20	8	9	10	3	11
Informative presentations	11	16	5	4	5	3	7
Inquiry	19	25	5	11	12	4	11
Lab experiments	5	10	5	4	6	1	3
Place-based learning	3	17	2	1	2	3	3
Readings	1	2	2	2	2	0	2
Student presentations	7	8	3	5	7	0	5
Technology-based learning	15	14	0	5	5	3	8

Table 2. Number of articles citing K-12 pipeline programs that use various discipline-specific techniques, organized by program discipline.

	Engineering	Environment & Geosciences	Health	Math	Science	Social Sciences	Technology
Black people	2	4	0	2	2	0	2
Indigenous peoples	1	5	1	1	2	0	4
Latinx	1	3	2	1	1	1	0
Location	0	0	2	0	1	1	0
Socioeconomic status	6	1	4	4	5	0	4
Underrepresented minorities	18	19	8	7	9	3	7
Women	8	2	2	3	3	1	2

Table 3. Number of articles citing pipeline programs that target various diversities, organized by program discipline.

objectives in the literature. Of the articles coded, 29% mentioned developing interest in the discipline as an objective and 21% enhancing diversity in the field of study. When broken down by discipline, all disciplines had at least 28% of articles cite developing interest as a goal; however, four out of the seven disciplines coded for (engineering, math, science, and technology) had less than 25% include enhancing diversity as an objective. The chi square analysis ($X^2(42)=44$, $p>0.05p=0.3927$), suggests no significant correlation between discipline and the pipeline program's goals.

The least cited objectives in the literature were "retention" (5%) and "improving self- efficacy" (3%). Retention appeared the most frequently in math-related programs (18%) and did not appear within the social sciences at all. The social sciences, as well as math, science, and technology, did not include improving self-efficacy as an objective at all.

"Teaching skills" are referenced in 11% of all articles coded, the fourth highest of the eight objectives coded. The health and social sciences disciplines, however, do not include teaching skills as an objective. Articles pertaining to the engineering, math, science, and technology disciplines were tied for the most articles citing teaching skills as an objective (29%) (Table 4).

Additional Findings— A Chi-square test of independence indicated that there was no significant correlation between program location and discipline ($X^2(49)=29$, $p>0.05$). A program's pipeline preparation method was not significantly related to program discipline ($X^2(14)=4.2$, $p>0.05$). Likewise, the presence or absence of a mentoring component was not significantly related

	Engineering	Environment & Geosciences	Health	Math	Science	Social Sciences	Technology
Access	4	3	0	2	2	0	2
Develop interest	17	23	8	7	9	2	9
Enhance diversity	6	16	7	2	5	2	5
Improve education	8	11	0	6	5	4	5
Improve self-efficacy	1	2	2	0	0	0	0
Provide opportunities	10	13	2	9	12	3	8
Retention	3	4	1	3	2	0	2
Teach skills	9	8	0	5	7	0	6

Table 4. Number of articles citing pipeline programs that have various objectives, organized by program discipline.

to program discipline ($X^2(7)=7.8$, $p>0.05$). Additionally, a chi-square test indicated no significant correlation between discipline and evaluation technique ($X^2(42)=41$, $p>0.05$, $p=0.534$).

Discussion

Age Group— Categorization of programs by grade level suggests there is an unmet need for elementary school-focused pipeline programs in E-STEM disciplines. Research has supported the importance of introducing science as early as possible in childhood to maximize brain development and to support curiosity, problem-solving, and social interaction. Exposure to meaningful science experiences in early childhood can nurture positive attitudes toward E-STEM and E-STEM professions that last into adulthood (Pendergast, 2017). Since many female and underrepresented minority students lose a sense of "science identity" in early adolescence (Patricia, 2017), providing opportunities for positive experiences in science before students reach middle school, through elementary-level pipeline programs for example, is one entry point for promoting equity in E-STEM.

Even more so than other disciplines, there is a lack of environmental science programs targeting elementary-aged students. As with the focus on active learning techniques, the focus on older grade levels may be a way that environmental science programs seek to establish the discipline as a rigorous scientific field. Ironically, this failure to reach elementary-aged students through environmental pipeline programs may inhibit the field more than it promotes it. The lack of elementary environmental pipeline programs neglects to capture the interest of and promote key skills in young potential environmental scientists.

Discipline-Specific Technique— The high representation of inquiry and hands-on learning components in K-12 pipeline programs is consistent with literature that demonstrates the positive effects of active learning approaches on cognitive processes. Inquiry and hands-on learning, along with other active learning techniques, have been demonstrated to engage students in learning, deepen students' content understanding, and help students retain new knowledge (Jin et al., 2011; Edwards, 2015).

Inquiry activities can be an especially valuable tool for promoting equity in E-STEM fields through K-12 pipeline programs. Inquiry activities positively affect all students', especially female students', personal confidence and subject interest in math and potentially other E-STEM disciplines (Tang et al., 2017). Moreover, inquiry-based learning approaches have been shown to engage a wider range of students without having a negative impact on the success of high-achieving students (Tang et al., 2017). English language learners can benefit from constructing their own understanding of material through inquiry activities, rather than reading from a textbook or listening to a teacher lecture (Gibbons, 2003).

There is particularly high proportion of environmental science articles that use inquiry and hands-on learning techniques. One possible explanation for this emphasis on active learning in environmental sciences is that the discipline's recognition as a "rigorous science" is more recent than the other disciplines studied. As a result, environmental science programs may be responding to added pressures to "prove" their basis in the scientific method and in research- supported pedagogical techniques.

The dearth of articles that reported coding as a discipline-specific technique is concerning considering the breadth of research that suggests that coding will be, or perhaps is, an essential skill in the modern work environment. The demand for coding skills is rapidly increasing, not only in the technology sector but also in the wider job market (Tuomi, 2018). While coding has typically either been viewed as applied math, a new language, or a technical skill (Burke, 2016), utilizing coding as a tool for probing other E-STEM disciplines may help a wider range of students learn the skill.

Demographic Targeted— Though our data did not suggest a significant relationship between discipline and the demographic targeted, studies have shown that certain racial and ethnic groups are biased toward certain fields due to cultural values and exposure to certain fields (Fouad & Walker 2005). For example, in a study comparing African American science teachers' preferences to White science teachers, African American teachers were more likely to prefer indoor laboratory settings, while White teachers were more likely to prefer outdoor field work (Sherman-Morris et al., 2012). These studies show the importance of tailoring a program's disciplinary goals and activities to the diverse groups being targeted.

It is telling that the environment and geosciences was one of the leading disciplines targeting Indigenous peoples, as Indigenous peoples have shown strong affinity for their environments and the natural world (Lewis, 1995). The literature explains that there is a lack of diversity, especially among Indigenous peoples, in the environment and geoscience disciplines (Riggs & Riggs 2003). When targeting specific groups, especially those with marginalized identities, it is important to understand the learning environments in which they learn best and to provide access to the materials and ideas that will be most meaningful for them (Kanu, 2006).

Objectives— Interestingly, though developing interest and enhancing diversity were the most frequently cited objectives in the literature, retaining students in those disciplines and giving them confidence to succeed (self-efficacy) were not as frequently cited. It could serve programs well to include improving self-efficacy as a goal, since studies have shown that students' own perception of their skills and success is directly related to whether or not they pursue a STEM field. One study explained how students with lower self-ratings of their math skills were less likely to pursue a STEM field (Nicholls et al., 2007).

While it is surprising that only 11% of programs cite teaching skills as a goal, it is possible that many programs left this goal unstated since learning a skill would be a natural outcome of the program. Regardless, research has shown the importance of giving students authentic learning experiences to "sustain [their] interest in the sciences" (Shultz et al., 2011, p. 15).

Implications for Practitioners— Practitioners can use this research to address gaps in the availability of K-12 E-STEM pathway programs. To address the need for elementary E-STEM pathway programs, pre-existing programs may open up enrollment to younger students or consider initiating new branches targeting elementary-aged students. Those considering initiating new pathway programs should prioritize younger grade levels. Practitioners of environmental science and geoscience programs should be particularly aware of the lack of elementary pipeline programs in their field and work to fill this unmet need. Inquiry and hands-on learning are important components of many pathway program curricula; however, programs in all disciplines should work toward integrating coding and other underutilized techniques. Additionally, practitioners should also research to understand potential participants' needs and align their objectives to the underrepresented group for whom the program is designed.

Future Research— This review lays a foundation for understanding the characteristics of K-12 pathway programs and the techniques these programs use to prepare students to enter E-STEM fields. Our findings open up several avenues for future research. After identifying a lack of programs for elementary aged students, we are curious to know the effectiveness of early intervention pipeline programs for engaging elementary-aged students in E-STEM fields. Additionally, there is a need to study best practices for elementary pipeline programs, as these may differ from best practices used for older students. Because so few programs utilized coding as a discipline-specific technique, we would be interested to learn how programs effectively integrate coding into the teaching of a wide range of E-STEM disciplines. More research is needed to understand various underrepresented groups' biases toward certain disciplines and their needs in regard to choosing and succeeding in certain disciplines.

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