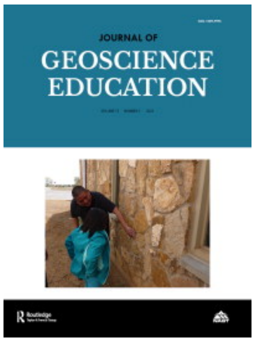

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Taylor & Francis Group

Journal of Geoscience Education

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/ujge20

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JOURNAL OF GEOSCIENCE EDUCATION
https://doi.org/10.1080/10899995.2023.2186762

Building science knowledge, identity, and interest using place-based learning with non-dominant urban undergraduate and high school students

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ABSTRACT
During remote learning due to the COVID-19 pandemic, we developed and implemented a place-based, 5E mini-unit for New York City high school and community college Earth science students, most of whom identify as belonging to non-dominant groups. As well as supporting standard science skills such as graphing and interpreting data, we leveraged active learning and culturally responsive pedagogies such as reasoning by analogy, storytelling, virtual field trips, and sketching. These strategies were aimed at developing science content and skills, science identities, and science interest. The mini-unit was taught over 6 to 7.5 hours. Pre-and post-surveys for 107 students from three schools showed significant gains in learning (38% increase; $p=<0.0001$). Science identity measurements increased slightly although they stayed relatively low. Science interest measurements were higher with small increases. Teacher influence and science classroom experiences ranked as the most important influencers of science interest. For 33 community college students, no correlation was found between content learning, science identity, and science interest. In this group, females and White students had higher scores for all three measures. Between pre- and post-survey, science identity increased, particularly for Black students, while science interest decreased for all but White students. For all students, overall increases between pre- and post-survey suggest the pedagogical approaches used during remote synchronous learning were successful at helping students grow as scientists.

ARTICLE HISTORY
Received 18 June 2022
Revised 13 February 2023
Accepted 28 February 2023

KEYWORDS
5E instructional model; community college; New York City; Earth science; climate change

Introduction

Students from non-dominant groups including racial and ethnic minorities, migrants, and lower income households, make up a vast proportion of urban populations in the United States. For example, 60% of New York City's population is nonwhite (U.S. Census Bureau, 2021). However, non-dominant groups are vastly underrepresented in science, technology, engineering, and mathematics (STEM) fields in higher education and the workforce. In the geosciences, almost 90% of doctoral degrees are awarded to White people (Dutt, 2020; Wilson, 2019) with little improvement over the past decades (Bernard & Cooperdock, 2018).

Inequity in educational opportunities in STEM contributes to reduced economic mobility for non-dominant groups. On a national scale, it reduces the country's ability to improve living standards, create economic growth, and drive innovation and global competitiveness (Freeman & Huang, 2015; National Science Board, 2021).

The COVID-19 pandemic and related shutdown that led to more than a year of remote learning for New York City students disproportionately impacted non-dominant communities. Challenges these students faced include taking the role of a caregiver by helping younger siblings with remote learning, lack of or intermittent internet access, sharing of digital devices with other household members, parents who were essential workers leading to lack of parental support, economic, housing, and food insecurity, trauma from death of family members, and mental health issues (Auxier & Anderson, 2020; Gaylord et al., 2020; Proto & Quintana-Domeque, 2021; Smith et al., 2020). This moment in time acutely highlighted the additional challenges and inequities non-dominant students face in their lives and education.

The initiative to improve representation in STEM has highlighted the need to build students' sense of belonging in science or *science identity* (e.g., Calabrese Barton et al., 2013; Stets et al., 2017). Science identity is the view of oneself as being a "science person" as well as gaining this recognition from others (Avraamidou, 2020; Carlone & Johnson, 2007; Vincent-Ruz & Schunn, 2018). Science identity is shown to play a role in students' engagement, meaning making, motivation, and persistence in learning science subjects and subsequent selections of science careers (e.g.,

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/10899995.2023.2186762.

Aschbacher et al., 2010; Chemers et al., 2011; Hazari et al., 2010; Trujillo & Tanner, 2014).

Further, developing students' knowledge and information-seeking behaviors or *science interest* is important for current and future participation in science-related activities (Ainley & Ainley, 2011a; Basu & Calabrese Barton, 2007). Students with a high science interest are curious about the scientific process, are willing to acquire scientific knowledge and skills, seek information about science, and have a sustained interest over time including considering a career in science (Organization for Economic Co-operation and Development (OECD), 2006, as cited in Ainley & Ainley, 2011b). Qualities that are thought to make up a strong individual interest in science are a combination of knowledge, affect, placed value (Hidi & Renninger, 2006) and finding enjoyment (Ainley & Ainley, 2011a).

Purpose and goals

The purpose of this work was to use pedagogical strategies that provided equitable ways (as discussed herein) of learning and demonstrating knowledge to build science content knowledge and skills, science identity, and science interest in a racially and linguistically diverse urban population of undergraduate and high school students during remote learning due to the COVID-19 pandemic. Our goals were to support students' growth as geoscience learners by building their scientific skills such as graphing, interpreting data, and map reading. In addition, we wanted to foster interest and confidence as scientists, particularly in a remote learning setting, with the underlying goal of attracting non-dominant students to science, in their future education and careers. We did this by making activities accessible, relevant, and fun.

About the mini-unit

The authors (a community college science professor, two high school science teachers, and a science teacher educator) developed a mini-unit totaling 6–7.5 hours that focused on the local glacial history of New York City and State to leverage place-based learning in order to increase student connections to the lesson content (Davies et al., 2021). The lessons were taught in a synchronous online setting. Highlighting natural processes and environments within the urban setting builds on what is familiar to students and connects science content to physical, social, and cultural influences. For example, students studied glacial features such as striations and erratics in Central Park, the boroughs of Manhattan, and Long Island. Utilizing place-based learning allows students to view the city in new contexts and highlight its value for study (Apple et al., 2014; Boger et al., 2014; Fleischner et al., 2017; Kirkby, 2014; Semken et al., 2017). Considering the high proportion of non-dominant students in urban areas, place-based learning can be impactful in increasing students' science interest and attracting these groups to science (Blake et al., 2013; DeFelice et al., 2014).

The lesson sequence was framed by the 5E instructional model of Bybee et al. (2006; Table 1 summarizes the components of the 5E instructional model we developed and lists activities and skills students engage in). It engaged multiple science practices and active learning opportunities shown to benefit all students, particularly those from non-dominant backgrounds (Freeman et al., 2014; Theobald et al., 2020). In the *Engage* phase of Bybee's instructional model, students are introduced to a phenomenon that promotes curiosity and surfaces prior knowledge. This allows the instructor to pre-assess understanding and is a starting point for learning. For *Explore*, students use their prior knowledge to generate new ideas when they participate in activities that connect concepts, processes, and skills, revealing any misconceptions. In *Explain*, students communicate their understanding from the previous phases and the instructor introduces them to relevant concepts and terminology. *Elaborate* introduces activities that challenge students to extend their learning and skills from the previous phases

Table 1. A summary of the purpose, learning objectives, learning activities, and skills students engage in for the 5E active learning lessons.

5E and purpose	Learning objectives	Activity	Skills students
Engage: Surface prior knowledge about glaciers.	Observe changes in glaciers and landscapes.	Compare images of glaciers in the past 50 years and observe and sketch a glacial landscape.	Observe, make comparisons, sketch.
Explore 1: Observe that glaciers move.	Calculate and interpret glacial advance and retreat rates.	Measure the rates of advance and retreat of Alaskan glaciers over time and graph the data.	Measure distances, tabulate data, calculate rates of change, interpret data, construct and interpret a graph.
Explore 2: Observe that glaciers shape the landscape.	Explain how a glacial landform is created.	Create glacial landscapes using models and explain using sketching how glacial landforms are created.	Use visual and analogue models, construct explanations, make predictions, determine components of a model and compare them to the real world.
Explain: Describe how glaciers create landforms.	Connect glacial processes and features with examples from students' everyday life.	Sketch glacial erosional and depositional features in New York State, create an analogy for how these features formed, and explain how they formed.	Sketch and describe a model, work in groups.
Elaborate: Apply knowledge to identify glacial features in New York State and connect this to past climate.	Connect glacial evidence in various locations in New York State to past climate.	Identify and interpret glacial landforms across New York State during a virtual field trip using Google Maps and connect to past climate history.	Use Google Maps/Earth to explore locations, analyze and interpret photographs.
Evaluate: Apply knowledge to identify other potential glacial features in the USA and Mars.	Interpret a new glaciated landscape.	Write a detailed report as a lead scientist, including descriptions and sketches of glacial landforms, formations, and processes.	Sketch, interpret information, write a report.

and apply it to new situations. In the final phase, *Evaluate,* students and instructors assess understanding related to achieving the learning outcomes. All teaching materials can be found in the supplementary materials section and Davies et al. (2021).

The overarching question for the mini-unit was "How do glaciers change the landscape?" Active learning opportunities that focused on developing science skills such as graphing, map reading, and interpreting data were included (National Research Council (NRC), 2012). We also used culturally responsive pedagogies to reflect on the diversity, identities, and experiences of all students and communicated to students that their varied experiences were an asset in learning (Gay, 2002). These activities included creating analogies to compare natural processes to students' everyday lives to enhance meaning making (Rivet & Kastens, 2012) and storytelling as a future scientist (Davies et al., 2021). A virtual field trip supported developing technology and map reading skills while building science interest (Jones & Washko, 2022; Shinneman et al., 2020). Students sketched at multiple points throughout the lessons which is shown to enhance student engagement, reveal understanding, and aid in organizing knowledge (Ainsworth et al., 2011). Finally, we attempted to incorporate fun in lessons to elicit positive emotional responses, thereby increasing the transfer of information to long-term memory storage (Ainley & Ainley, 2011a; Willis, 2007).

The mini-unit connected with a high school Next Generation Science Standards (NGSS) performance expectation, science and engineering practices, disciplinary core ideas, and crosscutting concepts. This included developing models to illustrate how surface processes operate at various scales to form continental features, opportunities to examine the relationships in Earth's systems that form glacial evidence, and analyzing and interpreting empirical evidence in order to make claims about and explain glacial phenomena over time.

Study population and setting

The mini-unit was taught to 179 Earth science students from one New York City community college (2YC), and two high schools (HS). Garnet Community College (GCC) had 52 students participate, Deep Valley High School (DVHS) had 63 students participate, and Douglass High School (DHS) had 64 students participate. Common traits across these students included high ethnic and racial diversity, and a high proportion of English language learners (ELLs). In addition, many were economically disadvantaged, had limited science literacy, and were first generation college students (Table 2). 107 or 60% of students completed both the pre- and post-surveys. For the 33 GCC students, English was a secondary language for 58% of students, 67% were ages 20–29, 21% were ages 18–20, 9% were ages 40–49, and 3% were ages 30–39 (Table 2). All student groups in this study completed the same assessments with the same items for both the pre- and post-survey.

Table 2. Demographics for all students from Garnet Community College.

Group	Combined (%)	GCC (%)	DVHS (%)	DHS (%)
Number	107	33	30	44
Hispanic/Latinx	39.6	24	54	36
Asian	23.8	39	8	36
Black	14.5	18	10	10
White	26.2	9	26	41
Race unknown	2.78	9	0	0
Non-resident	>1.8	6	no data	no data
Female	47.8	69	49	41
Male	53.1	31	51	59
ELL	>13.3	no data	6	28
Disabilities	>11.3	no data	18	15
Receive financial aid/ economically disadvantaged	74.7	84	54	82

Sources: Self-reported and National Center for Education Statistics (NCES, 2020), Deep Valley High School, and Douglass High School (New York State Education Department (NYSED), 2022).

Materials and implementation

The mini-unit was taught in synchronous online classrooms in two sessions (totaling 6 hours) over two weeks for the 2YC students, and 10 sessions of 45 minutes (totaling 7.5 hours) over two to three weeks for the HS students. Before instruction, lesson materials were modified by each instructor to meet the needs of their students. These adaptations included: redesign to match the format students were accustomed to, use of graphic organizers, slides and worksheets translated into Spanish and Chinese for ELLs, and simplification of aspects of lessons to fit pacing needs in classes as well as the limitations of the remote learning setting. Examples of adaptations include: students were asked to interpret a premade graph instead of creating their own graphs from data, group work being limited or students self-selecting to work in groups because they did not like working in online breakout rooms, and some short answer questions converted to multiple choice questions to streamline online grading.

Evaluation methods

Each of the three participating instructors administered the same assessment at the beginning and end of the lesson sequence to measure the development of content knowledge, science identity, and science interest. The assessment was given in a Google form with a link provided to each student to complete online (see supplementary materials). Pre- and post-survey written reflections for content learning were categorized by themes based on correct and incorrect answers and types of explanations (no explanation, some explanation, explanation uses scientific terminology; for example, glacial grooves and striations). For 33 2YC students, we used descriptive correlational analysis to compare student-generated demographic data to data about content knowledge, science identity, and science interest as the demographic groups are too small for statistical analyses.

Content knowledge

To measure students' content knowledge, we adapted the Keeley and Tucker (2016) Grand Canyon formative assessment probe to focus instead on glacial erosion, which is common to landforms in New York. The probe allowed students to pick the best answer in order to explain a phenomenon, one that made most sense to them based on their understanding of a process (Keeley, 2008). Instructors recorded each student's selected answer from one of six options and collected written responses from students that explained their thinking. Percentages of correct answers for each group and the whole group were then determined, and pre- and post-responses were compared. Student responses provided the reasoning that informed their answers and showed the progress of their learning with respect to the formation of landforms by natural processes including the use of appropriate vocabulary to explain these processes (Table 3).

In order to determine if the difference in correct answers between pre- and post- was statistically significant, we conducted a paired-samples proportions test. All scores with the correct answer were converted to one, while all other scores were converted to zero. We then conducted a z-test for two proportions two-tailed test using XLSTAT to determine *p*-values for all samples and also for each school group.

Science identity

Science identity was measured as a part of the pre- and post-survey using the science identity survey developed by Pugh et al. (2010). Four statements measure students' perceptions of themselves as scientists in the present and future using a Likert scale ranging from 1 to 5. The scores were then combined and averaged to determine a mean science identity value. A two-tailed t-test was used to compare the pre- and post-survey data for statistical significance. Cohen's D (Cohen, 1988) effect values were calculated for *p*-values equal to or below 0.05.

Table 3. Pre- and post-test content learning scores and theme analysis for all students and by student groups (GCC—Garnet Community College; DVHS—Deep Valley High School; DHS—Douglass High School).

Content assessment scores (%)								
Number	All (n = 107)		GCC (n = 33)		DVHS (n = 30)		DHS (n = 44)	
Scores (%)	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Fernando**	27.1	65.4	36.4	66.7	30.0	73.3	18.2	59.1
Emma	9.3	0.9	9.1	0.0	6.7	0.0	11.4	2.3
Lupe	3.7	1.9	0.0	0.0	6.7	3.3	4.5	2.3
Mayumi	42.1	21.5	30.3	24.2	43.3	10.0	50.0	27.3
Reginald	5.6	3.7	6.1	3.0	3.3	3.3	6.8	4.5
Zhang	12.1	6.5	18.2	6.1	10.0	10.0	9.1	4.5
P-value	<0.0001*		0.0200*		0.0270*		0.0001*	
Content theme scores (%)								
Correct. No explanation	3.7	3.7	9.1	3.0	3.3	10.0	0.0	0.0
Correct. Some explanation	15.0	16.8	18.2	27.3	13.3	10.0	13.6	13.6
Correct. Explanation uses scientific terminology	8.4	44.9	9.1	36.4	13.3	53.3	4.5	45.5
Incorrect. No explanation	11.2	10.3	6.1	9.1	3.3	3.3	20.5	15.9
Incorrect. Some explanation	30.8	7.5	30.3	6.1	33.3	13.3	29.5	4.5
Incorrect. Explanation uses scientific terminology	30.8	16.8	27.3	18.2	33.3	10.0	31.8	20.5

The correct answer is Fernando**.
*Represents data that is statistically significant.

Science interest

The science interest survey (SIS) developed by Lamb et al. (2012) was used to determine a science interest value for each student. The tool is broken into five subscales which tally to an overall science interest score. The subscales are: F (Family Encouragement), P (Peer Attitudes toward Science), T (Teacher Influence), I (Informal Learning Experiences), and S (Science Classroom Experiences). The SIS includes 19 items that are scored using a Likert scale ranging from 1 to 5. The survey was modified by removing questions 17 and 19 from Science Classroom Experiences which related to attitudes about being inside the classroom. These questions were not relevant because the survey was conducted during remote online learning. A two-tailed t-test was conducted on data from each school and all combined data to determine if the difference between pre- and post-testing was statistically significant. Cohen's D effect values were calculated for *p*-values equal to and below 0.05.

Validity and reliability

Keeley and Tucker (2016) outline the specific ideas that each of their assessment probes are trying to elicit from students and target one or more related concepts. They include a "best" or most scientifically acceptable answer for each probe. Following this model, we developed a probe that focused on a local outcrop that showed evidence of glacial erosion. We incorporated concepts related to rock formation, weathering, agents of erosion, and human impact in the possible choices, and reliability was determined by the authors agreeing upon the "best" answer which focused on glacial erosion due to rocks in ice sheets as well as a second best answer that focused on rocks causing grooves during floods following the ice age. Finally, explanations to support student answers were categorized by theme to further validate these results.

Pugh et al. (2010) ensured that science identity was distinct from other related constructs such as utility and self-efficacy using factor analysis which resulted in the 4-item scale. This survey was initially validated using grade 9 and 10 biology students from an urban setting of which a high percentage were White, while we applied this tool to non-dominant Earth science students of high school and college ages. For science interest, Lamb et al. (2012) established internal reliability for each subscale. While some subscales showed lower internal reliability than others, the overall internal reliability was adequate.

Results

107 or 60% of students completed both the pre- and post-surveys which assessed content learning, science interest, and science identity (Tables 3–6). 33 participants were non-major geology students from GCC, 30 were Earth science students from DVHS, and 44 participants were Earth science students from DHS. Assessments collected for GCC students took place over two consecutive semesters with a sample of 19 students participating in the first semester and 14 in the second semester.

Table 4. Examples of pre- and post-explanations for observations of rocks in Central Park from the same students.

Pre-content assessment	Post-content assessment
The rocks are formed in a way that is different from how I've seen they've formed in our labs whether (it) is from weathering, erosion, the way they cool down or where they're from…	Glaciers were the cause of these grooves and striations in these rocks.
It looks too smooth and well-worn and like some other "well loved" rocks I've seen other places.	The rock has striations and grooves that indicate ice and sediment once moved over it.
I think that the rock had that shape before the Central Park was built.	Because glacial grooves and striations are gouged or scratched into bedrock as the glacier moves.
When the glacier melted, the water along with rock fragments created these marks.	During moving of (a) glacier, rocks that were stuck in the glacier scratched the rocks in Central Park.
The rock has most likely formed from heat and stress.	Because of striations and grooves from glaciers.
The water can rub against the rocks which leads to the rock becoming more smooth and then eventually wearing away.	When the glacier moved it left striations and grooves due to rock and boulders getting stuck under the glaciers.
Erosion was the first thing that came to my mind as well.	Rocks sliding underneath ice sheet carved these lines.

Much of the initial reasoning draws on prior knowledge with students moving to a more accurate answer in the post-assessment.

Table 5. Science identity scores for all students and by student groups (GCC—Garnet Community College; DVHS—Deep Valley High School; DHS—Douglass High School) with 2-tailed T-test and Cohen's D size effect (Cohen, 1988) analyses.

Group	All data (n = 107)		GCC (n = 33)		DVHS (n = 30)		DHS (n = 44)	
Pre-/Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Mean	2.81	2.95	2.59	2.71	2.88	2.89	2.93	3.17
St. dev.	1.05	1.08	1.03	1.16	1.17	1.15	0.95	0.87
2-tailed P value	0.0112*		0.1276		0.8841		0.0096*	
Cohen's D effect size	0.1558						0.3712	
Present mean	2.82	2.96	2.53	2.62	2.79	2.69	3.08	3.41
Present st. dev.	1.05	1.08	1.06	1.21	1.16	1.12	0.91	0.93
2-tailed P value	0.0969		0.4503		0.5222		0.0198*	
Cohen's D	0.0736						0.5043	
Future mean	2.79	2.94	2.65	2.80	2.97	3.10	2.78	2.78
Future st. dev.	1.05	1.01	1.02	1.09	1.17	1.18	0.99	0.99
2-tailed P value	0.0529*		0.1503		0.4283		0.2150	
Cohen's D	0.2390							

*Represents data that is statistically significant.

Content knowledge

Between pre- and post-assessment, content knowledge increased by 38% overall and 30% for GCC students, 43% DVHS, and 41% for DHS students (Table 3). The z-test for two proportions two-tailed test determined the *p*-values were statistically significant ($p < 0.05$) for the combined data and for each individual school group.

In the pre-survey, GCC students had the highest content knowledge (36.4% had the correct response), followed by DVHS (30% had the correct response), while DHS had the lowest content knowledge (18.2% had the correct response). Comparing pre- and post-survey responses, students developed and refined their understandings of evidence of glacial processes in Central Park (Table 4). Analysis of 107 student explanations grouped by theme showed improvement consistent with the multiple

Table 6. Science interest means and subscale means for pre- and post-assessment grouped for all students (107), and for each of the three schools (GCC—Garnet Community College; DVHS—Deep Valley High School; DHS—Douglass High School) with 2-tailed T-test and Cohen's D size effect (Cohen, 1988) analyses.

All data								
Students	ALL (n = 107)		GCC (n = 33)		DVHS (n = 30)		DHS (n = 44)	
Assessment	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Mean	3.56	3.61	3.55	3.62	3.53	3.55	3.59	3.65
St. dev.	1.03	0.98	1.06	1.02	1.14	1.02	0.92	0.92
2 tailed P value	0.0391*		0.0790*		0.6939		0.6315	
Cohen's D	0.0497		0.0673					
F—Family encouragement								
Students	ALL (n = 107)		GCC (n = 33)		DVHS (n = 30)		DHS (n = 44)	
Assessment	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Mean	3.00	3.17	2.83	3.05	3.06	3.23	3.09	3.27
St. dev.	0.90	0.91	0.91	0.92	0.99	0.89	0.85	0.92
2 tailed P value	0.0006*		0.0158*				0.0437*	
Cohen's D	0.1884		0.2315				0.2032	
P—Peer attitudes toward science								
Students	ALL (n = 107)		GCC (n = 33)		DVHS (n = 30)		DHS (n = 44)	
Assessment	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Mean	3.20	3.22	3.37	3.26	2.97	2.96	3.30	3.30
St. dev.	0.91	0.88	0.88	0.94	0.87	0.89	0.87	0.85
T—Teacher influence								
Students	ALL (n = 107)		GCC (n = 33)		DVHS (n = 30)		DHS (n = 44)	
Assessment	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Mean	4.24	4.23	4.23	4.35	4.38	4.33	4.13	4.14
St. dev.	0.83	0.76	0.83	0.69	0.93	0.77	0.77	0.75
I—Informal learning experiences								
Students	ALL (n = 107)		GCC (n = 33)		DVHS (n = 30)		DHS (n = 44)	
Assessment	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Mean	3.44	3.54	3.46	3.58	3.38	3.46	3.56	3.61
St. dev.	1.02	0.95	1.13	1.02	1.20	0.98	0.82	0.90
S—Science classroom experiences								
Students	ALL (n = 107)		GCC (n = 33)		DVHS (n = 30)		DHS (n = 44)	
Assessment	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Mean	3.94	3.92	3.98	3.89	3.83	3.67	3.97	4.02
St. dev.	0.84	0.87	0.83	0.93	0.99	1.05	0.78	0.76

choice responses that documented either a correct or incorrect answer. Eight percent of students recorded the correct content answer supported by an explanation that used scientific terminology in the pre-survey. This increased to 45% in the post-survey. For all explanations that used scientific terminology (whether with a correct or incorrect answer) values increased from 39% to 62% between pre- and post-survey. On the bottom end of the spectrum, about 10% of students had incorrect responses and no explanation in both pre- and post-survey.

Science identity

The science identity mean for all students was below the middle score of 3.00 on the Likert scale for both pre- and post-survey (2.81; 2.95). GCC students had the lowest mean pre- and post-values (2.59; 2.71) while DHS had the highest (2.93; 3.17) (Table 5; Figure 1). As a whole, the science identity scores increased by 0.14 on the Likert scale between pre- and post-survey with a small effect size ($p = 0.0112$; Cohen's D = 0.1558). DHS students showed the greatest increase in science identity between pre- and post- (0.24) with a medium effect size ($p = 0.096$; Cohen's D = 0.3712). DVHS and GCC showed no statistically significant increases with p values >0.05.

The science identity survey statements can be broken into two categories: present (*I see myself as a science person*; *being involved in science is a key part of who I am*) and

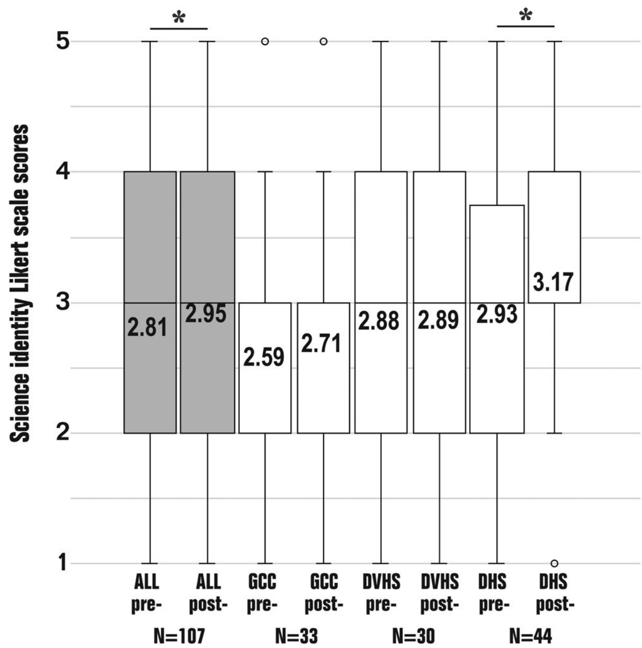

Figure 1. Box a plot showing science identity means for all combined data (n = 107; grey), GCC (n = 33), DVHS (n = 30), and DHS (n = 44) groups. Boxes represent the interquartile range. Lines represent the first and third quartile. Circles represent outliers. * represents data that is statistically significant.

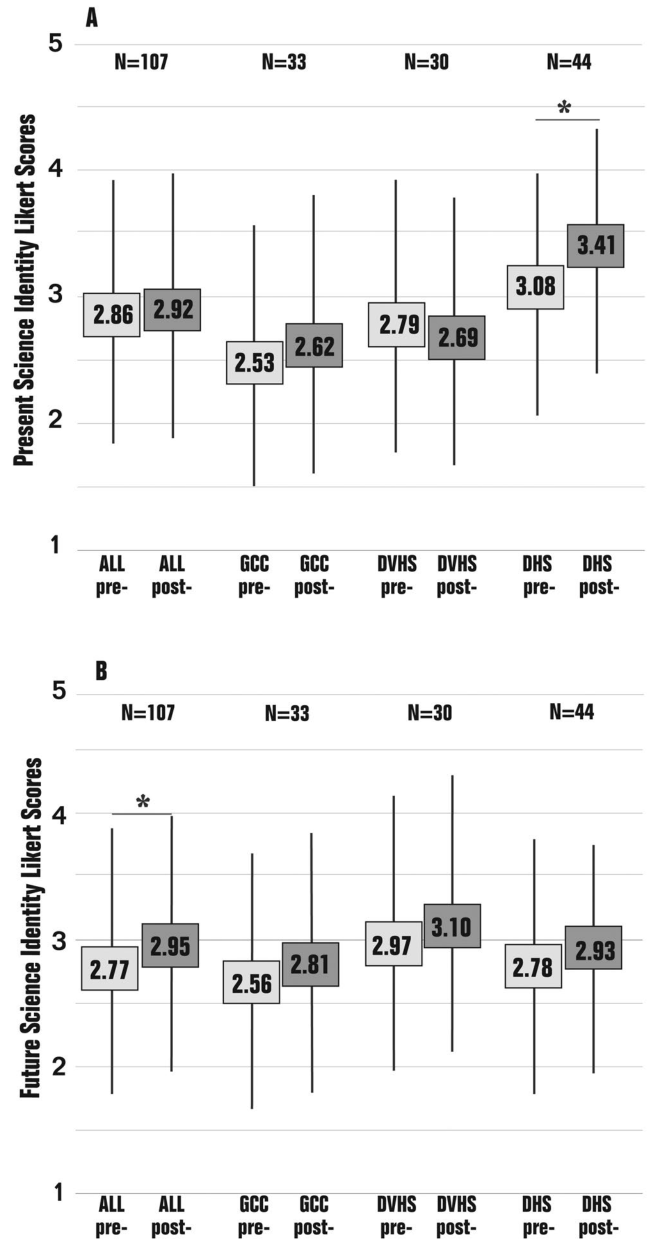

Figure 2. Science identity means and ranges for pre- and post-survey questions relating to student's science identity in the present (a) and future (b). * represents data that is statistically significant.

future (*I can see myself doing science in the future*; *I can imagine myself being involved in a science related career*). By grouping responses by present and future, we observe students' evolving senses of themselves as scientists (Table 5). For statements about the present, between pre- and post-science identity scores, DHS showed a significant gain (0.33) and a medium effect size ($p = 0.02$; Cohen's D of 0.5043), while changes to DVHS (-0.10) and GCC (+0.09) data were not statistically significant (Figure 2a). For statements about the future, the scores increased for all groups and were statistically significant overall; however, there weren't statistically significant changes for any individual school (gain = 0.15; $p = 0.0529$; Cohen's D = 0.2390; Figure 2b).

Science interest

Table 6 shows the science interest data means and standard deviations for pre- and post-survey grouped for all students (n = 107) and for each of the three schools. Unlike the science identity data, the science interest mean values were consistently above three on the Likert scale, and each school group had a mean value that is similar to the overall mean (Figure 3). Science interest increased between pre- and post-survey for all data and also for each school group. The overall mean and GCC mean had p values below 0.05 with a very small effect size (< 0.1), while DHS and DVHS did not show statistically significant changes.

All science interest subscales recorded values above the midpoint on the Likert scale with Teacher Influence having the highest values in the pre- and post-survey followed by Science Classroom Experiences (Table 6; Figure 4). When comparing the pre- and post-subscale data, there is little change except for Family Encouragement which shows a statistically significant increase with a small effect for all data (pre-3.00, post-3.17, $p = 0.006$; Cohen's D = 0.1880) as well as GCC (2.83, 3.05; $p = 0.0158$; Cohen's D = 0.2315) and DHS (3.09, 3.27; $p = 0.0437$; Cohen's D = 0.2032) with a small effect size. Increases found in DVHS data are not statistically significant.

GCC case study

To address relationships between student demographics and content learning, science identity, and science interest, we analyzed individual pre- and post-data for 33 students from GCC. We use descriptive correlational analysis to evaluate these relationships. The statistical significance of the stated

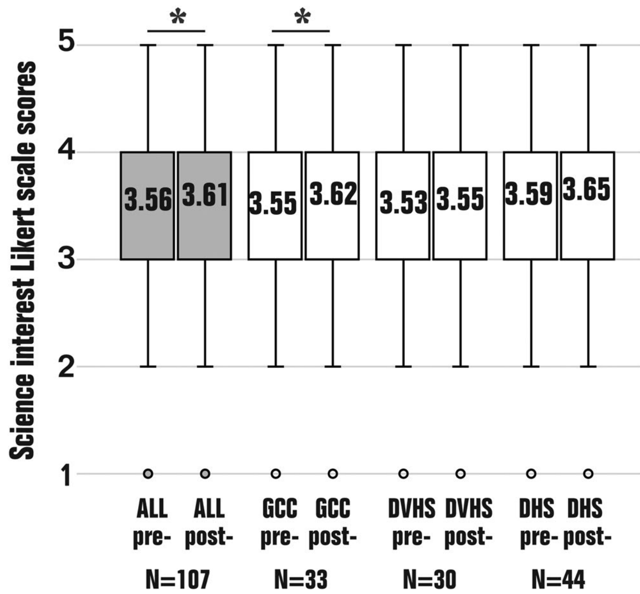

Figure 3. Box a plot listing science interest means for all combined data (n = 107; grey), GCC (n = 33), DVHS (n = 30), and DHS (n = 44) groups. Boxes represent the interquartile range. Lines represent the first and third quartile. Circles represent outliers. * represents data that is statistically significant.

differences is unknown because the demographic groups are too small for statistical analyses. For pre-survey by gender, 33% of females and 27% of males recorded accurate content knowledge, and for post-survey, 68% of females and 60% of males recorded accurate content knowledge. Compared to males, females had higher post-science identity scores (F:2.76; M:2.61) and post-science interest scores (F:3.60; M:3.46). For science interest subscales, females scored higher than males for all categories but Family Encouragement.

Science identity changes by gender between pre- and post-survey increased for both females and males (F:0.09; M:0.18). Present science identity increased more for females (F:0.16; M:0.05). Future science identity increased for both genders, most significantly for males (F 0.02; M 0.64). For science interest by gender, small decreases were found for both groups (-0.05).

Students with English as a secondary language, which represented 61% of the case study group, showed greater content learning gains: 30% had correct content scores in the pretest and 65% had correct scores in the post-test. For the remaining 39% of students in which English is their first language, 46% had correct content scores in the pretest and 69% had correct scores in the post-test.

Science identity differences between pre- and post-survey for English as a first language increased marginally more than students with English as a secondary language (0.17; 0.13). Pre- and post-gains in present and future science identities were greater for native English speakers versus English as a secondary language (present 0.33: 0.10; future 0.25:0.11). Differences in science interest scores slightly increased for native English speakers and decreased for English as a secondary language (0.07; −0.11).

Though the sample size for some racial identity groups is small, Black, White and Unknown students showed the highest gains in content learning followed by Hispanic/Latinx and Asian. Science identity scores increased between pre- and post- for all racial groups. Post-survey values are higher for Unknown (3.17) and White students (2.92) followed by Asian (2.73), Hispanic/Latinx (2.72), and Black (2.71). Present science identity for Black students increased the most between pre- and post-survey (0.42), while future science identity for Asian students increased the most between pre- and post-survey (0.38). Pre-science interest was highest for White students (3.98) followed by Hispanic/Latinx (3.67), Black (3.66), and Asian (3.53). Between pre- and post-survey, science interest increased for White and Unknown and decreased for all other groups.

Comparing content learning, science interest, and science identity

For the 66% of students with correct content scores after completing the mini-unit, science identity and science

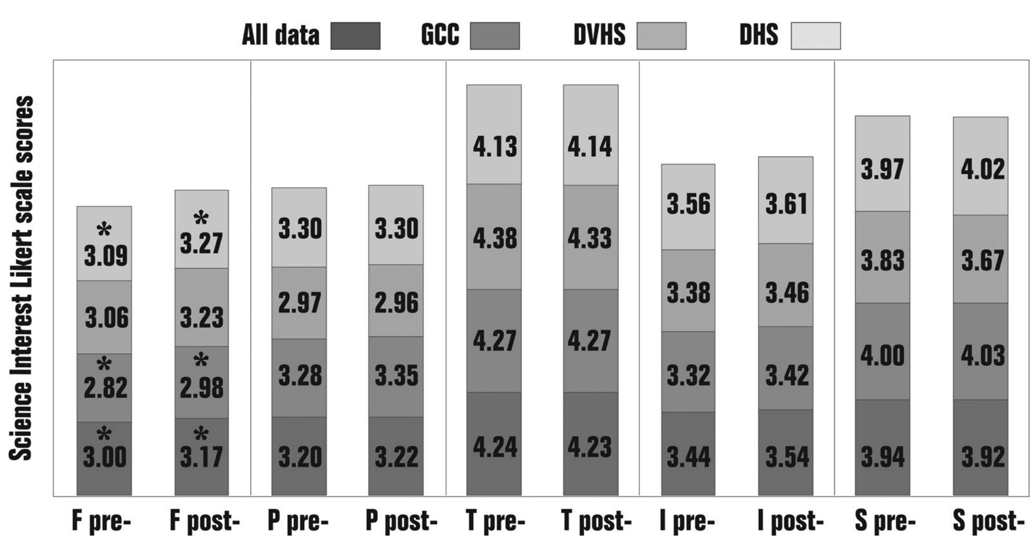

Figure 4. Science interest means by subgroup for all combined data (n = 107), GCC (n = 33), DVHS (n = 30), and DHS (n = 44). F (Family Encouragement), P (Peer Attitudes toward Science), T (Teacher Influence), I (Informal Learning Experiences), and S (Science Classroom Experiences). * represents data that is statistically significant.

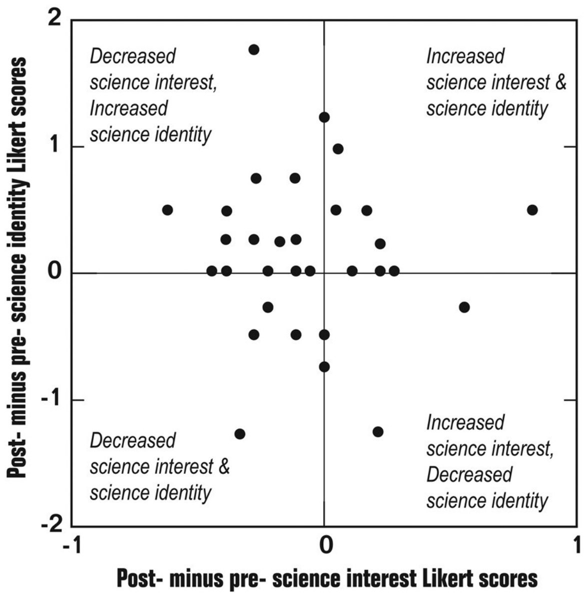

Figure 5. Changes to science identity and science interest scores between pre- and post-assessment for individual GCC students. The majority of students show an increase in science identity and a decrease in science interest (top left quadrant) followed by an increase in both variables (top right quadrant).

interest scores were not significantly different to the 34% of students with incorrect content scores. When we compare individual pre- and post-survey scores for science identity, 24% of scores decreased, 30% stayed the same, and 45% increased. For science interest, 55% decreased, 9% did not change, and 36% increased (Figure 5).

For post-science interest subscales, Teacher Influence and Science Classroom Experiences with the highest subscale values show a slight positive correlation. Family and Peer influences also show a slight positive correlation.

Discussion

Our data suggests that the 2YC and HS students in this study that are largely from non-dominant backgrounds have a high interest in science as shown by the scores above the mid-point on the Likert scale and small range of values within and across the three groups. However, science identity was highly variable within and across groups indicating more work needs to be done to build science identity in order to attract these students to higher education and careers in science. This study shares successful pedagogical strategies that can be used in remote and in-person settings for a diverse group of learners, as well as the importance of growing students' science interest and identities. Below we discuss the results of this study.

Content knowledge

For the 107 2YC and HS students in the study, post-survey scores for the 5E place-based mini-unit showed marked increases in content learning, with HS students showing higher gains compared to 2YC students. Further, post-survey written reflections were articulate in explaining processes of glacial weathering and erosion and, whether correct or incorrect, showed improvement in using scientific terminology to explain geological processes. About 10% of students either did not understand the questions, were not engaged, or did not understand the information presented in the lesson as indicated by little change in their scores for the least accurate answers between pre- and post-survey. 2YC non-major geology students showed the highest totals in both pre- and post-content knowledge which may be attributed to previous exposure to Earth science in high school.

As a group, DHS students, consisting of many ELLs, showed the lowest prior content knowledge and some of the greatest learning gains (Table 3). This suggests our use of equitable pedagogical methods including the 5E instructional framework grounded in place-based phenomena, a variety of activities to build authentic skills as scientists, balanced by sketching, reasoning by analogy to connect content to everyday phenomena, and storytelling, was successful.

Science identity

Consistent with previous studies of non-dominant groups in sciences (Hazari et al., 2013), science identity scores were below the mid-point on the Likert scale for all groups, with 2YC having some of the lowest scores. Science identity increased between pre- and post-scores with statistical significance and a small to medium effect size. This was largely driven by DHS students that showed the greatest gains in science identity. Considering we measured pre- and post-science identity in the space of several weeks and found small gains, if we adopted the same pedagogical approaches to teaching throughout the semester or year, we may expect these gains to be greater over time.

The lower science identity scores for 2YC non-major students may be because these students have already chosen a major of study that likely does not include a STEM field. This finding highlights that large gains in building science identity and attracting students to careers in STEM happens at younger ages, often before high school (Maltese & Tai, 2010).

When sorting the science identity survey by questions related to the present versus the future, students' self-perceptions as scientists between pre- and post-survey showed the highest scores and greatest increases in the present for DHS students, and the future for GCC and DVHS students. For the latter groups, this suggests many students consider science as a worthwhile endeavor in their futures. This is also supported by the values above the mid-point on the Likert scale for science interest scores. One possible explanation for the DVHS decrease in present science identity is because the mini-unit was implemented at the end of the school year and students may have been feeling burned out after a year of remote learning during a global pandemic.

Science interest

It is highly encouraging to find science interest scores were consistently above the mid-point on the 5-point Likert scale for all learner groups with a small cluster between 3 and 4. Science interest changed little between pre- and post-survey to suggest the values are not significantly influenced by our intervention.

When we examine the science interest scores broken into subscales, the higher values for Teacher Influence and Science Classroom Experiences indicate the importance of teachers and classroom environments for developing science interest as found by Osborne et al. (2003) and Maltese and Tai (2010). This was followed by subscales Informal Learning Experiences, Peer Attitudes toward Science, and Family Encouragement. A study using SIS on younger students also ranked Teacher Influence most highly, followed by Family Encouragement, Science Classroom Experiences, Informal Learning Experiences, and Peer Attitudes toward Science (Lamb et al., 2012) and supports the finding that over time, Family Encouragement has less influence on science interest while Peer Attitudes increase (Johnston & Viadero, 2000).

For the pre- and post-survey, an increase in the Family Encouragement subscale was the only category that was statistically significant with a small effect size. The lack of increase in other subscales is not surprising considering the pre- and post-surveys were administered in a short space of time. We speculate remote learning from home may have facilitated discussion about science with family members.

When comparing the science identity and science interest data for individual GCC students, the majority of students showed an increase in science identity and a decrease in science interest, while a smaller group of students show an increase in both. Students with English as an additional language scored higher for content learning but lower for science identity and science interest, highlighting the importance of building science interest and identity to grow the next generation of scientists and increase diversity in science.

Limitations

Limitations in this study include a small sample size and the short time frame over which the intervention took place and measurements were made. Scaling up this study to take place over several months, taking additional measurements weeks or months after the intervention, and having a control group could produce more meaningful data. Minor adaptations made to the lesson materials by each instructor could be considered a limitation to the consistency in the materials presented to each group. However, we do not consider this to be the case because the overall implementation fidelity was maintained although details were changed to match the student bodies. In addition, we used a five point measure for the SIS survey rather than four; the middle score option of "do not know" was included though Lamb et al. (2012) suggest removing it from the survey to increase the person separation index. We would also note that while this survey has been validated using K-12 students, it was used with 2YC students in this study. An additional limitation, which relates to the small sample size, is that statistical analysis does not allow for us to understand the nature of the relationships between variables, other than correlations. While the study suggests that this activity may improve students' participation in science later on, we do not show that there is a direct relationship from the increases in science interest and identity and participating in science courses or careers.

Explicit implications

This work is an example of success in teaching and learning in the time of remote learning during the COVID-19 pandemic. What we learned by creating this unit and measuring student learning, science interest, and science identity will inform curricula we develop and pedagogical strategies we will use in the future and in other contexts including online and in-person instruction.

The pedagogical innovations we developed were designed to support our two-year college and high school students largely coming from non-dominant groups that were hardest hit during the pandemic. We focused on using active learning and culturally responsive strategies to build knowledge, science identity and science interest.

The adaptations used by the various instructors can also be used by those interested in employing the innovations. These are:

1. Activities that build science skills such as measuring and graphing benefited from significant scaffolding such as the use of graphic organizers and providing formulae for making calculations. With the limited class time in the high schools, instructors did not have students construct graphs; instead, they provided completed versions and students worked together to interpret these graphs.
2. Sketching throughout the mini-unit was powerful. It was used to hone observational skills, visualize how glacial landforms are created, and to activate imagination. Sketching engaged students and allowed them to notice details inviting conversations about their observations. A drawing allowed students to express their ideas in a different way and instructors were able to gauge their understanding. In addition, it gave ELLs an opportunity to demonstrate understanding of the content without language challenges. We also found that drawing reduced the pressure to perform academically. In some of the classes, student sketches were shared with each other, allowing them to see what others were thinking and learn from each other.
3. Virtual field trips were easy to make and created a way to provide context to the content and apply it to new locations.
4. In the final *Evaluate* lesson, role playing as a scientist drove students to stretch themselves and create highly individual work.

Conclusions

The COVID-19 pandemic and move to remote learning highlighted the inequities that non-dominant students face in STEM education and created an urgency to join other educators in the effort to provide these students with tools and opportunities to grow as scientists.

We developed a place-based 5E mini-unit employing equitable pedagogical methodologies that aimed to build science identities and science interest for a racially and linguistically diverse group of urban non-major 2YC and HS Earth science students. This rich resource can be shared with high school and college educators and used as a model to build courses that promote learning, science identity, and science interest for diverse groups of learners.

Pre-and post-survey results showed increases in content knowledge. Mean science interest was above the mid-point of three on the Likert scale with little range and showed small increases between pre- and post-survey. For all student groups, Teacher Influence and Science classroom experiences ranked as the most important influencer of science interest. Science identity scores were highly varied and below the mid-point on the Likert scale, particularly for 2YC students. However, as a whole student groups showed gains between pre- and post-surveys in a small space of time, largely driven by the DHS group. This, together with high science interest scores, suggest our students are eager to engage as scientists when given the opportunity although a high science interest does not translate into an interest in being a scientist (DeWitt et al., 2014).

For 2YC students, those with English as an additional language were stronger in content learning but not science interest nor identity. In addition, females and White students had higher science identity and interest. Though this result is only from a small subset of students, it shows that further work needs to be done to increase the science identity and science interest in non-dominant students.

By comparing learning, science identity, and science interest in non-dominant students from different schools, we surfaced the uniqueness of each group which contributes to our understanding of each student group's strengths and needs for further growth. The collaboration between a community college professor, a teacher educator, and two high school Earth science teachers was very fruitful. The COVID-19 pandemic challenged educators in all settings in ways that no one could have anticipated. Together we brainstormed and developed strategies for implementing active online learning. We learned new pedagogical approaches, the theory and philosophy behind them, and about the glacial history of New York State.

Disclosure statement

The authors report there are no competing interests to declare.

Funding

This material is based upon work supported by the National Science Foundation under Grant No. (1852787). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. U.S. Department of Education under Grant Numbers U336S140026 and U336S190042.

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