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Authentic STEM research, practices of science, and interest development in an informal science education program

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Abstract

Background: Two critical challenges in science education are how to engage students in the practices of science and how to develop and sustain interest. The goal of this study was to examine the extent to which high school youth, the majority of whom are members of racial and ethnic groups historically underrepresented in STEM, learn the skills and practices of science and in turn develop interest in conducting scientific research as part of their career pursuits. To accomplish this goal, we applied Hidi and Renninger's well-tested theoretical framework for studying interest development in the context of a museum-based, informal science education (ISE) program. We used a mixed methods approach, incorporating both survey and interview data, to address three research questions: (1) As youth engage in authentic science research, do they develop perceived competence in mastering the skills and practices of science? (2) Do participants increase, maintain, or decrease interest in science research as a result of this experience? (3) How does participation in scientific practices manifest in non-program contexts?

Results: Our study yielded three main results. First, we found that participants developed competence in mastering several of the skills and practices of science. Strikingly, there was significant improvement in self-reported level of competency for 15 specific research skills. Second, we found that participants maintained their interest in scientific research over time. Our post-survey results revealed that one hundred percent of students were either excited about or expressed deep interest in scientific research. Based on a *Phases of Interest Development Rubric* developed for this study, most participants exhibited *emerging individual interest*. Finally, participants exhibited significant increases in the frequency in which they engaged in scientific practices outside of the program.

Conclusions: Our findings suggest that participation in authentic research in an ISE context affords youth critical opportunities for gaining mastery of several of the skills and practices of science, which in turn reinforces, and in some cases increases participants' interest in scientific research beyond the span of the program.

Keywords: Informal learning, Informal science education, Interest development, Science as practice, STEM

Background

Women and members of historically marginalized racial and ethnic groups remain underrepresented in STEM fields (Kricorian et al., 2020). According to the National

Science Board (2020), even though Black and Hispanic adults comprise 11.9% and 15.6% of the US population, these proportions do not correspond with the STEM workforce. Specifically, only 5.6% of Blacks and 7.5% of Hispanics hold careers in science and engineering. In contrast, Asians are overrepresented in science and engineering careers and White representation is similar to their proportion in the general population. Specifically, 19.8% of Asians and 65.0% of Whites hold careers in science and engineering careers yet Asians comprise 5.8%

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and Whites 64.1% of the US population, respectively. Furthermore, while the number of women with bachelors' degrees doubled in the past two decades, women remain underrepresented in the STEM workforce: only 29.0% of science and engineering careers are held by women, even though women comprise 51.5% of the US population (National Science Board, 2020). At the root of these disparities is inequitable access to STEM learning experiences essential for stimulating interest and exposure to the skills, vocabulary, and foundational concepts necessary to successfully engage in college-level STEM coursework, and for fostering a sense of belonging and identification within the scientific enterprise (National Research Council, 2009, 2015). Although there is a great deal that must be done to create equitable and inclusive practices that appropriately address social injustices, informal science institutions have led the way in reaching audiences historically underrepresented in STEM and have served as incubators of interest development (National Research Council, 2015).

Many informal science learning programs provide opportunities for participants to engage in *authentic science* (e.g., Chaffee et al., 2021; Flowers & Beyer, 2016; Habig et al., 2018). While there are multiple definitions of authentic science, there appears to be consensus with respect to two components: (1) authentic science includes experiences or practices in which students engage in real world science meaning that they explore phenomena that does not have predetermined outcomes and that connects to specific scientific issues in their lives; and (2) authentic science learning involves inquiry-based, student-directed experiences (Braund & Reiss, 2006). A certain type of authentic science integral to many informal science education (ISE) programs is one in which youth are positioned to engage in *authentic science research*. From our perspective, authentic science research is defined as experiences in which students engage as practitioners of science, that is, where they develop research questions and use specific tools and practices of science in real-world contexts to collect and analyze data, and to communicate their findings (Buxton, 2006; Habig et al., 2018; Weiss & Chi, 2019).

Because of the many restrictions associated with formal science education, including preparation for standardized tests and prescribed laboratory activities, authentic science is often more amenable to out-of-school and informal learning contexts than the formal classroom (Adams et al., 2012; Braund & Reiss, 2006). Authentic science research experiences in informal settings are typically those that parallel the practicing scientific culture of the institution; and are shaped by the unique resources and features available including access to scientists, technologies, tools, and a repository of specimens and artefacts

unique to each institution (Adams et al., 2012; Blanchard et al., 2020; Braund & Reiss, 2006; National Research Council, 2009). Authentic science research in informal settings might include real-world, student-directed experiences, such as conducting ecological surveys, observing the night sky, and extracting DNA from museum specimens (Braund & Reiss, 2006). For example, Project True (Teens Researching Urban Ecology) uses the resources of Fordham University and the Wildlife Conservation Society to provide guided inquiry-based projects in parks and greenspaces for pre-college students in the New York Metropolitan area (Aloisio et al., 2018). The Youth Astronomy Apprenticeship, an informal science education program facilitated by the Massachusetts Institute of Technology and the Smithsonian Astrophysical Observatory (Barros-Smith et al., 2012; Norland et al., 2009), and iTEAMS (Innovative Technology-Enabled Astronomy for Middle Schools), a project facilitated by the Harvard-Smithsonian Center for Astrophysics (Miller et al., 2011; Ward et al., 2012), both provide informal learning participants access to institutional resources, including robotic telescopes and guided mentorships. The Whitten-Newman ExplorOlogy Program, an ISE program facilitated by the Sam Noble Museum in collaboration with Oklahoma State University, provides high school students access to the Museum's resources, including fossil specimens and a fossil prep lab as well as research opportunities in which participants work side-by-side with paleontologists conducting paleontological fieldwork projects (Korn, 2011). These varied research experiences demonstrate how, in contrast to many formal education settings, the resources of informal science institutions are especially amenable to providing experiences that engage youth in authentic science.

Authentic research experiences in informal learning contexts, where youth engage as practitioners of science, are also thought to be critical for the development of science-affinity identities and for facilitating interest development (Adams et al., 2014; Blanchard et al., 2020; Gray, 2013; Habig et al., 2021). According to the National Research Council (2012), the skills and practices of science are described as three spheres of activity: (1) investigation and empirical inquiry; (2) construction of explanations using argument, analysis, or models; and (3) developing explanations and solutions. The theoretical rationale for engaging in scientific practices is based on the philosophy that students cannot fully understand scientific content and appreciate the nature of science without engaging in practices themselves. Some of the skills or practices of science that youth develop in ISE programs parallel those described in the Next Generation Science Standards (NGSS) and include asking questions, planning and carrying out investigations, analyzing

and interpreting data, using mathematics and computational thinking, constructing explanations, engaging in argument from evidence, and communicating information (National Research Council, 2012). As youth become competent practitioners—that is, as they become more confident in their abilities to work independently or to teach others the skills and practices of science that they develop while engaging in authentic science research—they begin to see themselves as a ‘science person’ and imagine themselves as a STEM practitioner (Habig et al., 2018). This theorization of identity stems from seminal writings of Carlone and Johnson (2007), where they operationalize identity as intersecting dimensions of performance, competence, and recognition. As youth engage in activities or performance, and as they become more competent, that is, as they “demonstrate meaningful knowledge and understanding of science content and [are] motivated to understand the world scientifically” (p. 1190), not only do they see themselves as people who can do science, others also recognize them as competent at science. We hypothesize that opportunities to practice authentic science research in an informal science setting contributes to the development of specific competencies and skills, and the recognition as one who can do science. Our standpoint is that this contributes to a deepening of interest in STEM.

Theoretical framework

Hidi and Renninger (2006) offer a well-tested theoretical framework for studying interest development in an ISE setting. According to their framework, interest is defined as a psychological state in which an individual has a predisposition to reengage in disciplinary content over time through sustained interaction with the environment (Hidi & Renninger, 2006; Krapp & Prenzel, 2011; Krapp, 2002, 2007; Renninger & Hidi, 2011). Hidi and Renninger (2006) identify four discrete phases of interest development: (1) triggered situational; (2) maintained situational; (3) emerging individual; and (4) well-developed individual interest. This framework is especially applicable for participants of ISE programs because these students typically enter a program with some interest in science (National Research Council, 2009), and the four phases model allows for a more nuanced approach to studying changes in interest.

The first two phases of interest development (situational interest) are characterized by focused attention and a positive reaction to environmental stimuli; it consists of a phase in which interest is triggered and a phase in which interest is maintained situationally (Hidi & Renninger, 2006). After interest is triggered (phase one), interest either grows (phase two) or wanes (returns to phase one) situationally based on extrinsic and intrinsic

factors including the type of learning environment, the amount of external support, and personal meaningfulness (Hidi & Renninger, 2006). The second two phases (individual interest) are characterized by a predisposition to reengage with disciplinary content over time; it consists of a phase in which there is emerging individual interest and a phase in which there is well-developed individual interest (Hidi & Renninger, 2006). In these two phases, an individual is less dependent on external support and interest development is more self-generated (Hidi & Renninger, 2006). Particularly important to note is that these are not stages. In the analogy of stages, one would graduate from one stage to another, but in the analogy of phases, one can move across phases bidirectionally depending on several factors (Renninger & Hidi, 2016). Many external factors grounded in sociocultural issues could influence shifting from later to earlier phases of interest. These include negative encounters with teachers of a particular subject (e.g., an unsupportive science teacher), feeling that the area of interest is not inclusive to certain races or gender types (e.g., females in the computer science field), or even an unsuccessful learning experience which lacked scaffolds and supports (e.g., participation in a badly managed robotics program) (Bell et al., 2013; Renninger et al., 2019; Renninger & Hidi, 2011).

From a sociocultural perspective, the potential for developing interest is in the learner, but it is the relationship that the individual has with the environment, including meaningful social interactions, that support interest development (Pressick-Kilborn, 2015; Renninger & Hidi, 2011). During earlier phases of interest development, interests are triggered by heightened affect and those triggers are provided by different stimuli, including social interactions, the design of activities, and instructional practices that help learners to engage in an activity (Renninger et al., 2019). Critically, a prerequisite to interest development is sufficient content knowledge to trigger an individual’s attention (Renninger & Hidi, 2016). With this in mind, to foster interest development during authentic learning experiences, it is often important to provide learners with sufficient support, because inquiry-based, self-directed learning can be overwhelming without sufficient content knowledge and expert guidance (Kirschner et al., 2006). One way to address this issue is through peer support and student/scientist partnerships (e.g., Aloisio et al., 2018; Barros-Smith et al., 2012). For example, the ‘Youth & the Ocean!’ (‘YO!’) program facilitated by the Lawrence Hall of Science in collaboration with the University of California, Santa Cruz utilizes graduate student mentors to guide cohorts of high school students as they engage in youth-driven marine science investigations (Weiss & Chi, 2019). Hence, from a sociocultural

perspective, opportunities to engage in meaningful social interactions with like-minded peers and guided training from expert adults are two important design features for triggering and maintaining the early phases of interest development (Pressick-Kilborn, 2015; Renninger & Hidi, 2011; Renninger et al., 2019). Later phases of interest development tend to develop gradually through repeated triggers from the environment, which may emanate from the above-mentioned design features (i.e., meaningful social interactions with like-minded peers and adults), but can also be self-generated (Renninger, 2000, 2010). Compared to other activities, individuals with well-developed interest reengage: (1) more frequently; (2) with greater depth of understanding and knowledge; (3) voluntarily; and (4) independently (Renninger & Hidi, 2016). In this study, we used a rubric based on these four behavior indicators to determine participants' phase of interest (to be described below).

Overview of research questions and rationale

Inspired by current theoretical understandings of interest development, the aim of this study was to examine the role of authentic science research as a programmatic feature in a museum-based ISE program. To accomplish this aim, we assessed how participation in this program impacted participants' self-reported skill development (i.e., perceived competence in learning the skills and practices of science), and their interest in science research as measured by frequency of engagement, depth of engagement, voluntary engagement, and capacity for independent engagement (the four behavior indicators that signal the latter phases of interest). Specifically, we addressed the following research questions: (1) As youth engage in authentic science research, do they develop perceived competence in mastering the skills and practices of science? (2) Do participants increase, maintain, or decrease interest in science research as a result of this experience? (3) How does participation in scientific practices manifest in non-program contexts? Based on our results, we used Hidi and Renninger's (2006) phases of interest development framework to discuss variation in participants' interest in pursuing scientific research following their informal science learning experience and use these findings to inform program design.

We were particularly interested in scientific research because there is a critical need for youth, including those who have been historically underrepresented in STEM, to consider careers in scientific research (Hurtado et al., 2009). A diverse research workforce is important because multiple perspectives help contribute to what scientific questions are asked, the nature and approach researchers consider in a study, and their implications for society. By embracing a diversity of voices, scholars can work

towards advancing our knowledge base and equitably addressing the needs of society. Critically, engagement in practices that embody the research process help youth, including those who do not choose a STEM career, to learn a set of transferable skills (National Research Council, 2013).

Methods

Study design

We applied a mixed methods approach, incorporating both quantitative and qualitative analyses, to study interest development of high school participants of a museum-based informal science education program. Our aim was to examine the role of authentic science research as a programmatic feature in a museum-based ISE program. For our quantitative analyses, we conducted baseline, midpoint, and post surveys to assess how participation in a museum program impacted participants' self-reported skill and interest development across the duration of the program. For our qualitative analyses, we conducted semi-structured interviews and administered open-ended questions, and then used deductive coding to analyze transcripts and to assess participants' phase of interest development using Renninger and Hidi's (2016) behavioral indicators (frequency of engagement, depth of engagement, voluntary engagement, and capacity for independent engagement). For both our quantitative and qualitative data, we used an expert panel to ensure content validity of our research tools. In the sections below, we provide a description of the study context, participants, instruments, procedures, and analysis strategies.

Context: the museum learning program

The Lang Program (Lang) is a 7-year out-of-school-time program at the American Museum of Natural History (AMNH). It has been in operation for over 21 years, admitting a new cohort annually. The program invites New York City youth, more than half who are members of racial and ethnic groups underrepresented in the sciences, to deeply engage with topics in the natural sciences through coursework and research experiences that leverage the museum's resources, which include hundreds of exhibits, objects, and collections, and access to scientists and science labs. Youth apply for Lang at age ten, when they are in the fifth grade. Museum staff visit schools and conduct outreach activities to recruit applicants who are motivated and interested in science, but who may not have opportunities or resources for informal science learning experiences within their communities. The goal is to create a gender-balanced, racially diverse cohort. At least 60% of participants belong to socioeconomic backgrounds that are near or below poverty level. Twenty youth are selected annually, and attend Lang

throughout middle and high school, meeting on alternate Saturdays during the academic year and for 3 weeks during the summer for a minimum of 165 contact hours per year. The program introduces participants to AMNH research disciplines—the biological sciences, Earth and planetary sciences, and anthropological sciences—while incorporating material from the over 40 permanent and special exhibitions. Starting in the 8th grade and then all the way through 12th grade, Lang youth can annually join research teams and work alongside AMNH scientists and educators conducting field- or laboratory-based projects that parallel AMNH research. Within the program, participants are afforded annual opportunities to participate in authentic science research by joining a research team; each team is facilitated by scientists, educators, and/or graduate students and meets approximately 60 h spread over several months.

Participants

In the present study, we focused on a cohort of 17 Lang students who participated in a landscape genetics research team during the summer and fall of 2018 (Table 1). Participants of this research team engaged in authentic science research by working collaboratively with a scientist, an informal science educator, and a graduate student. During this guided experience, participants worked in small teams of three to four students and engaged in practices that embody the research process. Each team developed original research questions, planned and carried out fieldwork and laboratory investigations, analyzed and interpreted their data using computational thinking, and communicated their findings to the public. The skills and practices that the participants learned included specific skills related to their respective projects such as DNA extraction or running

a gel electrophoresis as well as practices related to being a researcher such as conducting a literature review and keeping a lab notebook. The specific features of the landscape genetics research team, which we describe below, is a typical experience of participants of this museum program.

Description of the authentic science research program

Landscape genetics is a scientific discipline that merges the fields of population genetics and landscape ecology. The goal of the landscape genetics research team was to assess species diversity and population genetics of organisms along the waterways within and adjacent to New York City, areas that were part of participants' own communities and neighborhoods. In alignment with the Next Generation Science Standards (NGSS), which promotes a learning progression in which youth develop content knowledge by engaging in the discourse and practices that embody the research process (National Research Council, 2012), students engaged in the practices of science by partaking in both laboratory and fieldwork. As part of this process, youth collected specimens from a set of locations surrounding New York Harbor. At each location, youth also collected data on an array of abiotic factors including salinity, dissolved oxygen, temperature, and turbidity. Following sample collection, participants engaged in laboratory work that incorporated genetic techniques including DNA extraction, polymerase chain reaction (PCR) amplification, and DNA sequencing to identify organisms. DNA sequencing was used to inform bioinformatics analyses, yielding patterns of genetic variation among the littoral communities of New York Harbor. Thus, by engaging in the scientific process, youth developed several specific skills and practices of science, which they used to address several fundamental questions about the landscape genetics and biodiversity along New York Harbor and its surrounding waterways. Some of the original research questions formulated and addressed by participants during this process included: In what ways does the landscape of New York impact the distribution and genetic variation of organisms along its shoreline? How and to what extent do varying abiotic environments along the shoreline of New York impact the distribution and genetic variation of different organisms? How do the genetic architectures and the distribution of littoral organisms of New York Harbor change over time? Thus, through this authentic research experience, participants used their results to communicate their findings to the research community and to better understand whether Queens, Bronx, and Manhattan are biogeographical barriers to species dispersal and distribution and whether the landscape of New York

Table 1. Self-reported race, gender, and grade level of program participants of the landscape genetics research team (n = 17)

Demographic Information	Total
<i>Race/ethnicity</i>	
Asian	4
Black of African Descent	3
Latina/Latino	6
White	4
<i>Gender</i>	
Female	7
Male	10
<i>Grade</i>	
10	4
11	6
12	7

Table 2 Landscape genetics research team curriculum

Session	Curriculum
Summer Session (July–August; Mon–Fri)	Lab and fieldwork safety Workshop 1: Lab basics (how to micropipette) Workshop 2: Keeping a lab notebook (guest graduate student) Workshop 3: Developing an authentic research question (museum hall activity) Workshop 4: How to read a journal article Workshop 5: Journal club discussion (guest scientist) Workshop 6: Morphological measurements (guest scientist) Workshop 7: How to organize an annotated bibliography Workshop 8: Background research (writing workshop) Workshop 9: Measuring biodiversity (e.g., alpha diversity; beta diversity; gamma diversity; Jaccard’s similarity index) Workshop 10: Analyzing biodiversity using the R Program for Statistical Computing Fieldwork with scientists and graduate students (sample collection, water quality testing, urban biodiversity surveys along multiple waterways within and adjacent to New York City)
Fall Session (September–December; Saturdays)	Review of safety protocols Workshop 11: DNA Extraction and polymerase chain reaction (PCR) Workshop 12: Gel electrophoresis and DNA sequencing Workshop 13: Writing an Introduction (guest graduate student) Workshop 14: Writing the Methods and Materials section Workshop 15: Bioinformatics Workshop 16: Statistical analyses Workshop 17: Writing the Results section (guest graduate student) Workshop 18: Writing the Discussion section Workshop 19: Poster design Workshop 20: Presenting a scientific poster Ongoing: Lab work with scientists and graduate students; data analysis; bioinformatics; creating figures and tables; writing a research report; preparing for poster symposium

influences genetic variation and patterns of speciation. An outline of the landscape genetics research team curriculum is depicted in Table 2.

Instruments and procedures

To test our hypothesis that opportunities to practice authentic science research in an informal science setting contributes to participants’ competence in mastering the skills and practices of science, which in turn stimulates interest development and motivates youth to consider pursuing these interests beyond the duration of the ISE experience, we applied a mixed methods approach. For our quantitative analyses, participants were administered surveys during three timepoints (Fig. 1): (1) before participation in the research team (baseline survey); (2) following the summer session (midpoint survey); and (3) following the fall session (post survey) (see "Methods" supplement to view all three surveys). The surveys consisted of both Likert-type and open-ended questions and were comprised of three sections: (1) skills and practices; (2) interest in scientific research; and (3) engagement in the practices of science beyond the span of the program (at home, with friends outside the program, and in school). We summarize each research question, sources of data, and analysis tools in Table 3.

The Likert-type survey questions that focused on the skills and practices of science included questions to gauge whether the focal youth perceived themselves as competent practitioners over time. Altogether, youth were surveyed from a scale of one to four on 17 skills and practices that were introduced during their participation in this research team (Table 4). Participants rated their experience using each scientific practice by selecting one of four responses: (1) need to learn; (2) need to review; (3) I can do it without review; and (4) I can do it without review AND I can also teach others. Four Likert-type survey questions focused on interest development (Table 4; Additional file 1); participants rated their interest in scientific research based on one of four categories: (1) not interested; (2) might be interested; (3) excited about; and (4) deep interest. Finally, four variables were used to assess participants’ engagement in scientific practices in non-program contexts (Table 4). Specifically, we surveyed on a scale from one to four how often participants: (1) read scientific articles; (2) discuss science with friends; (3) discuss science with family; and (4) think

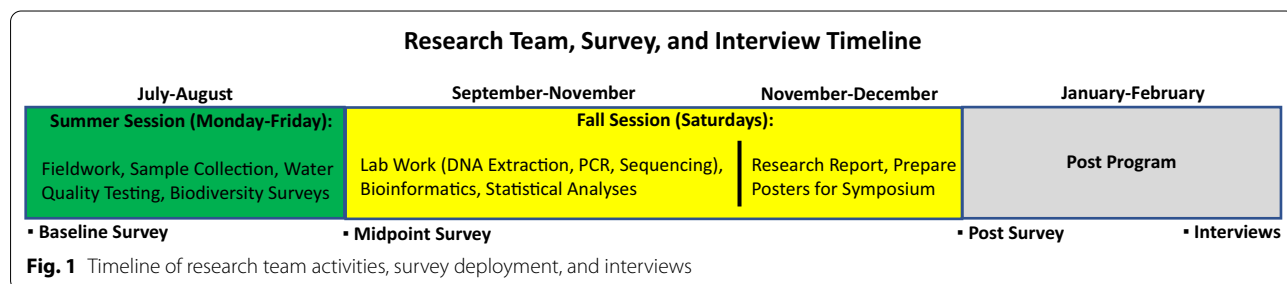


Table 3 Research questions, sources of data, and analysis tools

Research Question	Sources of data	Analysis Tools
Research Question 1: As youth engage in authentic science research, do they develop perceived competence in the skills and practices of science?	Pre-, mid-, and post-survey	Repeated measures ANOVA; Tukey post-hoc test
Research Question 2: Do participants increase, maintain, or decrease interest in science research as a result of this experience?	Pre-, mid-, and post-survey Interview questions	Repeated measures ANOVA; Tukey post-hoc test Phases of interest development rubric; deductive analysis
Research Question 3: How does participation in scientific practices manifest in non-program contexts?	Pre-, mid-, and post-survey Interview questions	Repeated measures ANOVA; Tukey post-hoc test Phases of interest development rubric; deductive analysis

Table 4 Predictor variables and response variables modeled for quantitative analyses (repeated measures ANOVA)

Research Question	Response Variables	Predictor Variables
Research Question 1: As youth engage in authentic science research, do they develop competence in the skills and practices of science?	Skill 1: Conducting a literature review Skill 2: Annotated bibliography Skill 3: Pipetting Skill 4: Keeping a lab notebook Skill 5: Water quality testing Skill 6: DNA extraction Skill 7: Polymerase Chain Reaction (PCR) Skill 8: Gel electrophoresis Skill 9: Standard morphological measurements Skill 10: Sample collection Skill 11: Species identification Skill 12: Writing a research proposal Skill 13: Constructing phylogenetic trees Skill 14: R Program for Statistical Computing Skill 15: Measuring biodiversity Skill 16: Creating a research poster Skill 17: Writing a peer-reviewed research article Composite: Combination of all 17 skills	4-point scale measured over three timepoints (baseline, midpoint, and post participation): 1 = Need to learn 2 = Need to review 3 = I can do it without review 4 = I can do it without review AND I can teach others
Research Question 2: Do participants increase, maintain, or decrease interest in science research as a result of this experience?	Interest in scientific research	4-point scale measured over three timepoints (baseline, midpoint, and post participation): 1 = Not very interested 2 = Might be interested 3 = Excited about 4 = Deep interest
Research Question 3: How does participation in scientific practices manifest in non-program contexts?	Practice 1: Reading scientific articles on my own Practice 2: Discussing research with my friends outside of school and Lang program Practice 3: Discussing science research with my family Practice 4: Thinking about science-related questions Composite: Combination of 4 scientific practices	4-point scale measured over three timepoints (baseline, midpoint, and post participation): 1 = Rarely 2 = Sometimes (monthly) 3 = Often (weekly) 4 = Very often (almost daily)

about science-related problems outside of the program. For this analysis, students rated frequency of engagement outside of the museum program by selecting one of four responses: (1) rarely; (2) sometimes (monthly); (3) often (weekly); or (4) very often (almost daily). For our quantitative analyses, we used mixed effects repeated measures ANOVAs to assess how the following changed over time: (1) perceived competence in mastering the skills and practices of science, (2) interest development, and (3) scientific practices in non-program contexts.

Because research suggests that survey questions alone might not adequately indicate level of interest (Renninger & Hidi, 2016) and that younger and older youth might interpret the same survey differently (Frenzel et al., 2012), Renninger and Hidi (2016) recommend that questions about interest development should incorporate triangulation methods including open-ended questions and the collection of additional data to confirm or refute closed-ended survey data. Thus, 1 month after the culmination of the landscape genetics research team, we conducted semi-structured interviews with all 17 participants to

better understand their level of interest development with respect to scientific research. For logistical reasons, we scheduled five different interview dates with three to four participants per interview. For each of these interviews, we intentionally grouped students with similar levels of interest (based on the results of our quantitative surveys) to minimize the impact of participants influencing each other's answers.

For our qualitative analyses, we used a theory-driven approach to analyze the interview data and open-ended questions. Specifically, we analyzed the transcripts (BH, PG) using deductive coding based on the four behavioral indicators of interest development (Renninger & Hidi, 2016): (1) frequency of engagement; (2) depth of engagement; (3) voluntary engagement; and (4) capacity for independent reengagement. Deductive analysis is a top-down qualitative approach in which a researcher uses predetermined codes, in this case the four behavioral indicators, and uses these data to work from theory to hypotheses (Bingham & Witkowsky, 2021; Creswell, 2013). Accordingly, we used this approach to identify specific behaviors of participants indicative of their phase of interest development and to evaluate our hypothesis that authentic science research contributes to interest development.

From these multiple sources of data, which included baseline, midpoint, and post surveys conducted by museum staff, audio recordings of interviews (administered by BH), and qualitative analyses of these documents based on deductive coding (BH and PG), we used the *Phases of Interest Development Rubric* (Table 5) to quantify the phase of interest development of each participant (BH and PG) based on each of the four behavioral indicators. We then averaged these four scores to calculate each participant's overall phase of interest development. By doing so, our quantitative analysis of the qualitative data (interview transcripts) was not a replacement for the qualitative analysis, but instead served as a complementary methodology to better triangulate our data (Fakis et al., 2014).

Validation and reliability

To ensure the content validity of our survey tools, interview questions, and interest development rubric, a panel of scholars was recruited to evaluate whether these instruments were adequately representative of the topics under investigation. The criteria for the selection of panel members included experience and familiarity with: (1) ISE research; (2) literature on interest development; and (3) survey development. Following the assessment process, we used the survey data (both forced choice and open-ended questions) and interview data to inform our rubric. Specifically, we used the rubric to identify each

participant's phase of interest development and from our interview data, we extracted individual examples of behavioral indicators representative of the different phases of interest development. To assess inter-rater reliability of the *Phases of Interest Development Rubric*, we used both percent agreement (Lombard et al., 2002) and Cohen's kappa (Cohen, 1968). Percent agreement was 76.6% and Cohen's kappa (k) was 0.69 both indicative of substantial agreement (Cohen, 1968).

Statistical analysis

All survey data analyses were conducted using R version 4.02 (R Core Team, 2021). We conducted mixed effects repeated measure ANOVAs using the *nlme* package (Pinheiro et al., 2006). Each response variable (Table 4) was modeled individually using three timepoints: (1) baseline survey; (2) midpoint survey; and (3) post survey. To get an overall sense of how participants perceived themselves as practitioners of science, we also calculated composite scores for skills and practices of science and practices in non-program contexts (Table 4). We used the *multcomp* package to perform Tukey post-hoc tests to compare differences between timepoints (baseline survey vs. midpoint survey; baseline survey vs. post survey; midpoint survey vs. post-survey). Although the use of parametric statistics in the analysis of interval or ratio scale data is commonly practiced and has been found to be robust (Norman, 2010), we acknowledge that we violate the assumption that the dependent variables are continuous variables.

Results

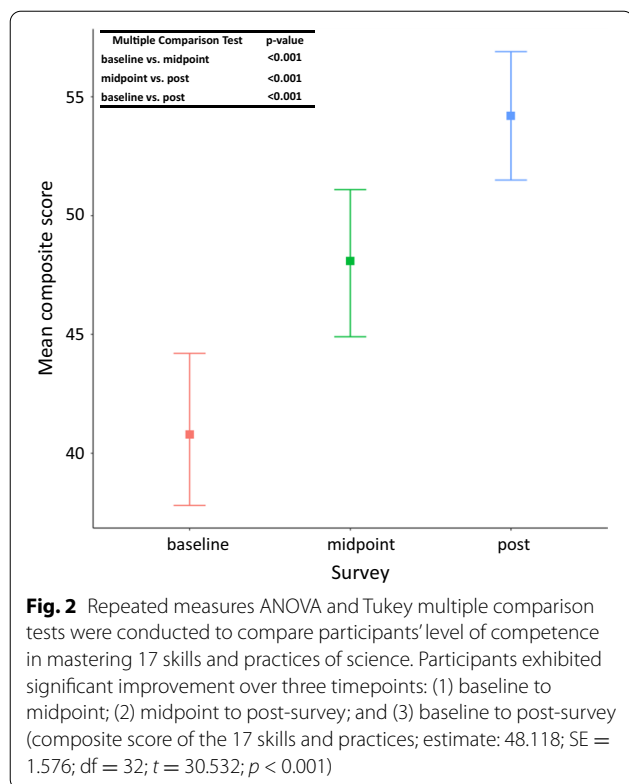
Here we revisit each research question that was presented in the Introduction and present the results of corresponding analyses. We also present our findings from the *Phases of Interest Development Rubric* and discuss specific behaviors we identified that were indicative of a specific phase of interest development.

RQ1 As youth engage in authentic science research, do they develop perceived competence in the skills and practices of science?

Our first research question addressed whether participants developed competence in mastering the skills and practices of science. To address this question, we conducted a repeated measures ANOVA to assess participants' self-reported skill development across the duration of the program. In support of the idea that engaging in practices of science that embody the research process is essential for learning (National Research Council, 2012), participants exhibited significant improvement in their self-reported ratings of competence in mastering the

Table 5 Phases of interest development rubric

Phases of Interest Development Rubric				
Behavioral Indicator	(1) Triggered Situational	(2) Maintained Situational	(3) Emerging Individual	(4) Well-Developed Individual
Frequency of Engagement	Poor attendance (<75% attendance) Preferred less time to participate in activity or project	Somewhat consistent attendance (≥75% attendance) Preferred same amount of time to participate in activity or project	Consistent Attendance (≥ 90% attendance) Preferred slightly more time (1 or 2 days) to participate in activity or project	Exemplary attendance (100% attendance unless extenuating circumstances) Preferred more time (> 2 days) to participate in activity or project
Depth of Engagement	Minimal knowledge and understanding of the content Needs a lot of support from an expert to engage in activity or project	Some knowledge and understanding of the content (need to review) Needs some support from an expert to engage in activity or project	Consistent knowledge and understanding of the content (do not need to review) Needs minimal support from an expert to engage in activity or project	Exemplary knowledge and understanding of the content (do not need to review and can teach others) Only occasionally needs support from an expert to engage in activity or project
Voluntary Engagement	Participates in activity or project only when it is mandatory Does not want to reengage in activity or project following completion	Occasionally participates in activity or project beyond mandatory periods Might want to engage in activity or project following completion	Sometimes participates in activity or project beyond mandatory periods Most likely wants to engage in a similar type of activity or project following completion	Nearly always participates in activity or project beyond mandatory periods Definitely wants to engage in the same activity or project following completion
Capacity for Independent Engagement	Does not engage in activities related to the project outside the scope of the program Does not have plans to engage in this activity or project in the future (college or career)	Occasionally (< 1/month) engages in activities related to the project outside the scope of the program Might want to engage in this activity or project in the future (college or career)	Regularly (monthly) engages in activities related to the project outside the scope of the program Expressed interest in engaging in this activity or project in the future (college or career)	Consistently (> 1/month) engages in activities related to the project outside the scope of the program Expressed definitive interest in engaging in this activity or project in the future (college or career)



skills and practices of science over time (composite score of the 17 skills and practices; estimate: 48.118; SE = 1.576; df = 32; $t = 30.532$; $p < 0.001$; Fig. 2). Moreover, for all 17 participants, there were statistically significant ($p < 0.05$) increases in levels of competency for 15 of 17 individual skills and practices and a marginal increase ($p < 0.10$) for one of 17 individual skills (Figs. S1–S17). Notably, Tukey post-hoc tests revealed significant increases in levels of competency for several individual skills including but not limited to using a pipette (baseline vs. post: $p = 0.006$), DNA extraction (baseline vs. post: $p < 0.001$), keeping a lab notebook (baseline vs. post: $p < 0.001$), measuring biodiversity (baseline vs. post: $p < 0.001$), and using the R program for Statistical Computing (baseline vs. post: $p < 0.001$).

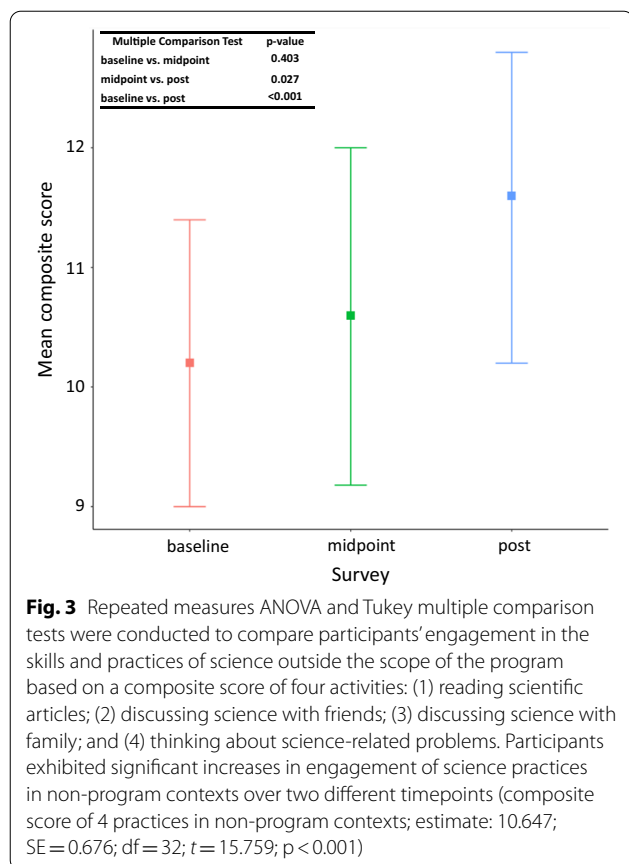
RQ2 Do participants increase, maintain, or decrease interest in science research as a result of this experience?

Our second research question focused on whether participants' interest in scientific research increased, was maintained, or decreased as a result of this experience. A comparison of our baseline survey (mean = 3.64; SD = 0.49) to our post survey (mean = 3.70, SD = 0.47) revealed that participants maintained their interest in scientific research over time (1 = not interested; 2 = might be interested; 3 = excited about; 4 = deep

interest). Based on post-survey results, one hundred percent of the students rated their interest in scientific research as either 3 (excited about) or 4 (deep interest). Specifically, five of 17 participants were excited about scientific research and 12 of 17 expressed deep interest in scientific research. Finally, we triangulated both interview and survey data to identify participants' interest in scientific research 1 month after the culmination of the research team. Based on the *Phases of Interest Development Rubric* (Table 5), we found that two participants exhibited *maintained situational interest* in scientific research, 13 participants exhibited *emerging individual interest*, and two participants exhibited *well-developed interest*. Overall, the mean rubric score of all 17 participants was 2.96 (SD = 0.455) indicative of *emerging individual interest*. Notably, the mean rubric score for participants who self-identified as Africans of Black descent or Latina/o was 2.78 (SD = 0.45) and for females 3.09 (SD = 0.62), both indicative of *emerging individual interest*. The mean rubric score varied for each behavioral indicator: on average, participants rated highest on *frequency of engagement* (mean = 3.21; SD = 0.61) followed by *depth of engagement* (mean = 2.97; SD = 0.54), *capacity for independent engagement* (mean = 2.94; SD = 0.68), and *voluntary engagement* (mean = 2.74; SD = 0.53).

RQ3 How does participation in scientific practices manifest in non-program contexts?

Another way to measure interest development is to assess the behavioral practices of program participants (Renninger & Hidi, 2016). To do so, we assessed whether participants engage in the skills and practices of science outside the scope of the program. Specifically, we tested whether participation in the following activities increased, was maintained, or decreased over time during non-program contexts: (1) reading scientific articles; (2) discussing science with friends; (3) discussing science with family; and (4) thinking about science-related questions and problems. Indeed, in support of the idea that participating in authentic research and engaging in the practices of science stimulates interest development over time, participants exhibited significant increases in the frequency that they engaged in scientific practices outside of the program (composite score of 4 practices in non-program contexts; estimate: 10.647; SE = 0.676; df = 32; $t = 15.76$; $p < 0.001$; Fig. 3; Figs. S18–S21). In addition, based on our post-survey results (1 = rarely, 2 = monthly, 3 = weekly, 4 = almost daily), we found that on average, participants discussed scientific research with their family and read about scientific research on their own on an almost weekly basis (discussing science with family: mean = 2.81; SD = 1.10; reading scientific



articles: mean = 2.63; SD = 0.87) and that they discussed scientific research with their friends and thought about science-related questions and problems in non-program contexts at least once a week (discussing science with friends: mean = 3.00; SD = 0.71; thinking about science-related questions: mean = 3.31; SD = 0.85).

Categorizing of the participants in the four phases of interest development

Our mixed methods results, which is a combination of deductive analysis supplemented by quantitative data, allowed us to consider where these 17 participated landed within the four phases of interest development.

Situational interest in scientific research

Two of the 17 participants exhibited behaviors indicative of situational interest in scientific research. As a reminder, situational interest refers to a phase of interest development in which students exhibit focused attention and a positive reaction to environmental stimuli; it consists of a phase in which interest is triggered and a phase in which interest is maintained situationally (Hidi & Renninger, 2006). The first phase, *triggered situational*

interest, is characterized by the development of a novel interest, which is “triggered” by an environmental stimulus that captures the attention of the learner (Renninger et al., 2019). The second phase, *maintained situational interest*, is characterized by attention to an environmental stimulus over a sustained duration of time (Renninger & Hidi, 2019). Because many young people enter ISE programs with personal motivation to engage in science activities, unsurprisingly, there were no participants identified as exhibiting *triggered situational interest* (Phase 1). However, two participants were identified as exhibiting *maintained situational interest* (Phase 2).

The participants who exhibited *maintained situational interest* typically sustained interest over extended periods, but also needed external support from an expert (Pressick-Kilborn, 2015; Renninger et al., 2019). They also occasionally participated in research beyond mandatory periods, and they indicated that they might want to independently engage in the activity or project in the future (Renninger & Hidi, 2016, 2019). For example, student 2 and student 11, the two participants we identified as exhibiting *maintained situational interest*, both expressed the need for external support when engaging in the skills and practices of science and appeared to be slightly less independent than their peers. Student 11 said that she “always prefers to have somebody there” and student 2 stated, “I would definitely have someone supervise me...I definitely need a supervisor to help me out”. While both participants were still open to engaging in science research in the future, they were also considering other fields of study. Student 2 further exhibited signs of *maintained situational interest* when he expressed interest in participating in additional sessions beyond the scope of the program. Likewise, Student 11 exhibited additional evidence of *maintained situational interest* when she attended one of the voluntary sessions offered by the program and when she participated in a group chat with her research team to discuss their project outside of the program. Our findings are consistent with research showing that early phases of interest development are largely dependent on external support from adults and peers (Pressick-Kilborn, 2015; Renninger et al., 2019) and aspects of the curriculum including collaborative group work (Palmer et al., 2016; Renninger et al., 2019).

Individual interest in science research

Fifteen of 17 (88.2%) participants exhibited behaviors indicative of individual interest in scientific research including seven of nine (77.78%) students who self-identified as Black of African descent or Latina/o, and six of seven (85.71%) females. Individual interest is characterized by a predisposition to reengage with disciplinary content over time (Hidi & Renninger, 2006); it consists

of two phases—*emerging individual interest* (phase 3) and *well-developed individual interest* (phase 4). Of the 15 participants who exhibited individual interest in scientific research, 13 were identified as exhibiting *emerging individual interest* (phase 3) and two were identified as exhibiting *well-developed individual interest* (phase 4).

Participants with *emerging individual interest* exhibited evidence of self-generated interest and typically revisited content voluntarily (Renninger & Hidi, 2016, 2019; Renninger & Riley, 2013). Although they still sometimes needed external support from peers and experts, especially when confronted with challenges, individuals with *emerging individual interest* typically exhibited mastery over the content and required minimal intervention (Renninger & Hidi, 2016, 2019). For example, student 12 learned how to code during his research team experience. He shared that he spent countless hours at home learning how to use the R Program for Statistical Computing to analyze his data. Critically, when he faced obstacles, he stated, "...having [the instructor's] email was important for me, having contact with [the instructor] so I could be able to catch up at home." Like Student 12, other participants with *emerging individual interest* also tended to exhibit a capacity for independent reengagement, which was evidenced when they revisited content when not required. For example, student 8 described how she revisited content in non-program contexts:

Yeah, I would say, before we started doing these research projects, I wouldn't really so much look into science articles...it never really crosses my mind. But, doing these research projects and searching up articles, you know, I realized that there's such fascinating research out there that I would like to learn more about and especially now. Sometimes my parents and I will discuss biology and like I'll search up articles and I'll show it to them.

Finally, participants with *emerging individual interest* also expressed a desire to revisit content in the future (Renninger & Hidi, 2016, 2019). Indeed, of the 13 participants who exhibited *emerging individual interest* in scientific research, 10 expressed interest in pursuing research as a career when interviewed 1 month following the culmination of the program.

Two participants exhibited evidence of *well-developed individual interest* in scientific research, defined as an "enduring predisposition to reengage with...content over time" (Hidi & Renninger, 2006, p. 115). *Well-developed individual interest* is characterized by four key characteristics: (1) high frequency of engagement; (2) high depth of understanding of disciplinary content; (3) voluntary engagement; and (4) a propensity for independent reengagement (Renninger & Hidi, 2016). Two participants,

students 14 and 17, exhibited the four characteristics of *well-developed individual interest*. First, both participants exhibited exemplary attendance and indicated a desire for further engagement. For example, student 14 reflected, "I wanted like more field days and more lab work, but also more time to work on the paper itself and also the poster, because I feel like we could've made it better. I think we could've done more in-depth analysis of our data too." Second, the two participants with *well-developed individual interest* also demonstrated depth of understanding. For example, student 17 stated, "I would feel really comfortable teaching the material that I've learned...I would be really confident in teaching it". Indeed, for 15 of 17 research skills, student 17 indicated on the post-survey that she did not require further review and that she was confident that she could teach these skills to others. Student 14 indicated the same for 13 specific skills. Third, the two participants with *well-developed individual interest* exhibited evidence of voluntary engagement as they both consistently attended non-mandatory sessions to work on their respective research projects. Finally, the two participants continually reengaged in content outside the program and beyond. For example, student 17 stated, "I read science articles almost every day and I feel like that interest has been pretty constant." Student 14 stated, "I write for a teen science journal...I recently wrote an article about climate change and lobsters." Indeed, our post-survey results indicated that students 14 and 17 discuss scientific research with friends and family and think about science-related questions and problems almost daily. Beyond the program, these two participants provided additional evidence of independent reengagement as they both applied for research programs at other ISE institutions following their experience in the program. Moreover, student 14 indicated that she plans to conduct research on ancient DNA when she attends college. While student 17 is interested in a career in medicine, following this experience, she said that she is considering pursuing an MD–PhD in the future.

Discussion

One of the most critical challenges of educators is to figure out how to develop and maintain students' interest (Hidi & Harackiewicz, 2000). In this study, we found that participation in authentic research in an ISE context affords youth critical opportunities for gaining mastery of several of the skills and practices of science. Notably, we found that participants reported significant improvements in their level of competency for 15 specific research skills (Fig. 1; Figs. S1–S17). Our triangulated data suggest that mastery of these skills in turn reinforced, and in some cases increased participants' interest in scientific research beyond the scope of the

program. Indeed, based on the *Phases of Interest Development Rubric* developed for this study, the mean rubric score of all 17 participants was 2.96 indicative of *emerging individual interest*. Our data suggest that two aspects of participation in authentic science research programs are particularly important for building a science identity and for fostering interest development: (1) engagement with skills and practices that embody the research process, and (2) research experiences relevant to participants' lives.

Engagement with skills and practices that embody the research process

The practices that participants learned in the museum program parallel those described in the Next Generation Science Standards (NGSS) (National Research Council, 2012). Specifically, in alignment with NGSS, participants were afforded opportunities to develop their own original research questions, to collect specimens in a local natural environment, to analyze and interpret their own data, and to communicate their findings to the museum community. As youth gained competence in mastering the skills and practices of science, this reinforced their interest in scientific research. For example, one participant (student 6) stated, "I think going out into the field and collecting data was like very attractive and then coming back into the lab and analyzing the data...not just having data given to you or having specimens given to you, that made it more personal and made it like more enticing." Similarly, another student (student 8) stated, "actually going out and collecting the fish on our own with the proper instruments and, you know, collecting the DNA and getting all dirty with the mud and everything...I did PCR, I did gel electrophoresis, you know, and like I think that's really cool and so I definitely increased my passion for science." Going deeper, two specific scientific and engineering practices of NGSS that participants developed during the museum program were "analyzing and interpreting data" and "using mathematics and computational thinking" (p. 3). During the program, museum youth learned how to use different biodiversity indices (e.g., alpha diversity, Simpson index, Shannon–Weiner index, evenness), the R Program for Statistical computing, and phylogenetic trees to analyze and interpret data mathematically and computationally. In fact, participants reported significant increases in their level of competence for 15 specific research activities aligned with NGSS scientific and engineering practices. However, for two activities, gel electrophoresis and conducting a literature review, we did not find significant improvement in participants' level of competence over time. For gel electrophoresis, we believe this was probably because of time constraints. During the program, the scientist mentor

had to run these gels overnight after the participants had gone home; hence, students did not have sufficient time to develop this practice independently. For the activity of conducting a literature review, there was a marginal ($p < 0.10$), albeit nonsignificant, increase in competency over time. This finding might be explained by the fact that many participants entered the research team with prior experience conducting literature reviews either in the museum program and/or in their formal science education classes.

Research experiences relevant to participants' lives

Our results suggest that participation in authentic science research relevant to participants' lives helps to augment interest development (Renninger & Hidi, 2016). In support of this idea, Renninger et al., (2019) identified "personal relevance" (p. 4) as a trigger for interest development in a recent study of an informal, out-of-school time biology program. Accordingly, Furtak and Penuel (2019) emphasize the importance of research foregrounded by personal and community concerns. In the present study, participants conducted research in the waterways within and adjacent to New York City. Many of these study sites were spaces that participants were intimately familiar with while others, although not far, were situated in spaces where participants had never visited before. This setting afforded participants the opportunity to develop and investigate authentic, individualized questions based on phenomena relevant to their lives (Furtak & Penuel, 2019; National Research Council, 2013), including how to protect local ecosystems and how to conserve local biodiversity. One participant (student 8) stated that he is interested in a career in marine biology and that he was inspired by the research he conducted in New York Harbor: "I want to do [marine biology] as a career and for the rest of my life so that really opened my eyes...seeing how rigorous it was, I just wanted to keep on doing it and continue researching." Following his participation in the Lang research team, student 8 signed up for a program in his high school, where he can continue independent research in his community based on the work he started at the museum. Adams and Branco (2017) further emphasize the importance of local parks as settings for authentic science research investigations. They write: "Parks are spaces where lived experiences and science learning could come together in ways not afforded by brick and mortar informal science institutions" (p. 338). Indeed, participants of the current study conducted investigations in their own backyards, the greenspaces and waterways of the New York metropolitan area and used these spaces to answer student-driven research questions relevant to their lives.

The role of authentic science research in identity development

Through their participation in authentic science research, museum participants were afforded opportunities to develop their science identities. In accordance with Carlone and Johnson's (2007) concept of identity development, museum participants operationalized their science identity in three ways: (1) by engaging in rigorous research (performance); (2) by gaining mastery of the skills required to self-direct their learning (competence); and (3) by communicating their research to scientists, educators, and to the public-at-large at a culminating public poster presentation held in one of the museum halls (recognition). This authentic research experience presented students the opportunity to enact a particular identity and to make visible their competence to others. A similar study of undergraduates also found that engagement in authentic research (performance) contributed to gains in the mastery of several skills and practices of science (competence) including data collection, data analysis and interpretation, and experimental design as well as confidence in communicating science to others (recognition) (Thiry et al., 2012). Moreover, the authors of this study reported an association between authentic science research and the development of epistemological growth, gains in understanding the nature of scientific knowledge, and dispositions for being patient, thinking through problems, and learning from failure. These findings suggest that the STEM skills and practices that participants gain mastery of during ISE programs are "transferable competencies" that extend between and beyond STEM disciplines (Carnevale et al., 2011). In support of this idea, Flowers and Beyer (2016) conducted a study of high school participants of the Tyson Environmental Research Fellowship (TERF), an ISE program facilitated by Washington University and the Missouri Botanical Garden. Following this study, the authors hypothesized that the program's sequence of educational exploration followed by immersion in authentic research were "transferable to other science disciplines and research environments" (p. 120). Similarly, our interview data suggest that providing youth opportunities to practice science in one discipline may be a cross-cutting experience (National Research Council, 2013). One participant (Student 1) articulated this point: "[Participation in the research team] did like reinforce the fact that I want to do research in college, not necessarily research in like environmental science, but definitely just like the idea of research and working on research projects and having that collaborative environment." We add to a growing body of literature suggesting that authentic research experiences at the high school and early

college levels prepare youth to develop a more refined understanding of what they may want to engage in as they navigate through college and beyond and develop their science identities.

The role of informal science institutions in promoting interest development.

We found multiple lines of evidence supporting our hypothesis that participation in an informal science research team contributes to interest development. First, our quantitative analyses indicated that participants entered the research team with a strong interest in research (baseline survey: mean = 3.64; SD = 0.49) and that their interest was sustained throughout this experience (post-survey: mean = 3.70, SD = 0.47). This is not a surprising result as participants of ISE programs typically enter a program with prior interest in science (National Research Council, 2009). However, even though students self-select for informal learning programs, it is often quite challenging to sustain participants' interest for extended periods of time (e.g., Blanchard et al., 2018; Bonnett, 2018; Klein & Tisdal, 2014). Second, as suggested by Renninger and Hidi (2016), we also measured interest development by assessing the behavioral practices of program participants outside the context of the program. Specifically, we found that participants exhibited significant increases in the frequency that they engaged in scientific practices in non-program contexts including reading science articles and discussing science research with their friends. Finally, our interview data further supported our hypothesis that engagement in authentic science research contributes to interest development. Following participation in this program, two participants exhibited *maintained situational interest* in scientific research, 13 participants exhibited *emerging individual interest*, and two participants exhibited *well-developed individual interest*. Overall, the mean rubric score based on the *Phases of Interest Development Rubric* was 2.96, which is indicative of *emerging individual interest*. Furthermore, our interview data indicated that participation in the museum program either reinforced or augmented participants' interest in engaging in scientific research in college. These findings are consistent with studies of other ISE programs that report an association between engagement in authentic science research and interest development (e.g., Barros-Smith et al., 2012; Salto et al., 2014; Weiss & Chi, 2019). Our triangulated data, in accordance with these studies, suggest that authentic research experiences in an ISE context are important vehicles for reinforcing and augmenting interest development.

There are many different perspectives on how to develop and maintain students' interest (for a comprehensive review, see Renninger & Hidi, 2011, 2019).

Hecht et al. (2019) characterize interest as a “concept or word used in daily vernacular to describe a feeling of attraction or excitement for something outside of ourselves” (p. 692). According to this definition, “... interest embodies the desire to get to know more about something or someone” (Hecht et al., 2019; p.692). This conceptualization of interest development is a derivation of the influential work of Valsiner (1992), who describes interest as an “ongoing process in the life-world of the person” (p. 32). In the present study, our conceptualization of interest development was largely based on the foundational work of Hidi and Renninger (2006). We found that Hidi and Renninger’s (2006) conceptualization of interest development was especially applicable for a museum-based ISE program. This is because many students enter ISE programs with an interest in science, and the four-phase model allows for a more nuanced approach for studying interest development. Furthermore, because survey questions alone are inadequate for measuring interest development, the four behavioral indicators proposed by Renninger and Hidi (2016)—frequency of engagement; depth of engagement; voluntary engagement; and capacity for independent reengagement—were the basis for developing our *Phases of Interest Development Rubric*. Critical scholarship from Brigid Barron (2006) supports this conceptualization and provides us with three interlocking key ideas about examining interest development from a learning ecology framework. These ideas, which she terms “conjectures”, are as follows: (1) a variety of resources and experiences can spark and sustain interest in learning; (2) people not only choose but develop and create learning opportunities for themselves once they are interested assuming they have time, freedom, and resources to learn; and (3) interest driven learning activities are boundary-crossing and self-sustaining. In support of these ideas, several studies of ISE programs in which youth are exposed to institutional resources and varied authentic experiences, have reported a positive correlation between participation in these programs and future engagement in STEM major and STEM careers (e.g., Aloisio et al., 2018; Habig et al., 2018; Winkleby et al., 2009).

While our results are based on only one study of one group of students from New York City, our findings are comparable to other studies of ISE programs across multiple major cities including Boston (e.g., Barros-Smith et al., 2012); Chicago (e.g., Chi et al., 2010); San Francisco (e.g., Weiss & Chi, 2019); and St. Louis (e.g., Flowers & Beyer, 2016). The program design principle of engaging students in authentic science research is ubiquitous in our nation. For example, 24 institutions in New York City collectively engage 500 students annually in science research mentoring programs (Chaffee, et al.,

2021). While such experiences can be supported by formal K-12 institutions, we think that the unique attributes of informal science programs located in museums, universities, and even hospitals make these settings more amenable for fostering interest in science research. This is largely because many informal science institutions, including museums, zoos, universities, and gardens, already have a research department in place and a plethora of resources, including access to scientists, technologies, tools, and a repository of specimens and artefacts unique to each institution (Adams et al., 2012; Blanchard et al., 2020; Braund & Reiss, 2006; National Research Council, 2009). Thus, many ISE programs are well suited for providing youth opportunities to engage as communities of scholars in authentic research that parallel the practicing scientific culture of the institution. Ideally, partnerships between K-12 schools and a variety of formal and informal institutions will bring together assets and affordances that most benefit students (e.g., Hamerness et al., 2017; Weinstein et al., 2014).

Limitations

We acknowledge that there are several limitations to our study. First, one limitation of this study is the possibility of self-selection bias as students typically enter the research team with an interest in and prior experience in scientific research. A second limitation is the problem of institutional selection bias as students are not selected randomly to participate in this program. These two limitations, self-selection and institutional selection of participants, are quite common in ISE programs (National Research Council, 2009). Therefore, we think that Hidi and Renninger’s (2006) model is especially appropriate for this type of population, because it provides a more nuanced approach for studying interest development. A third limitation of this study was that interviews were only conducted after the culmination of the program. Therefore, we are missing baseline qualitative data, which would have allowed for identification and comparison of phases of interest development before and after participation in the research program. In the future, we are interested in re-interviewing students when they are in college to see how their phase of interest development changed longitudinally. A fourth limitation of this study was our modest sample size ($n=17$). We accounted for this limitation by applying a mixed modeling approach. Indeed, the application of modeling-based methods, specifically with small sample sizes, has been found to yield less biased standard error estimates and higher statistical power than comparable methods (McNeish & Harring, 2017). Finally, a fifth limitation of our study was our lack of a comparison group, which prevents us from making any causal links between design principles and participants’ outcomes (Habig, 2020).

Conclusions and future directions

In support of our hypotheses, we found that authentic engagement in the research process helps youth become more confident in their abilities to work independently and/or to teach others the skills and practices of science and in turn, reinforces and possibly augments interest development. Moreover, our interview data suggest that engagement in authentic research was a transferable experience—that is, by providing youth opportunities to become practitioners of science in one discipline, it reinforced or motivated students to consider research in other disciplines. We suggest an investigation of “transferable competencies” (Carnevale, et al., 2011) as an area of future research to test whether the skills and practices that students learned during their research experience extend to other scientific disciplines and research environments. Furthermore, we found that the *Phases of Interest Development Rubric* (Table 5) was a useful tool for gauging interest development and was especially appropriate for our study population, because it allowed for a more nuanced approach for studying interest development. Although we were satisfied with the application of the rubric, perhaps the development of an even more sensitive scale could capture more fine-scaled changes in interest development. For future application, we suggest that ISE educators use the four key behavioral indicators—frequency of engagement, depth of engagement, voluntary engagement, and capacity for reengagement—as a formative assessment for gauging interest development in real time and thereby informing program design. While our rubric was project specific, we think that many components can be adapted by other ISE programs and modified based on the unique attributes of individual programs. Finally, we suggest that ISE practitioners use the *Phases of Interest Development Rubric* longitudinally to inform why participants increase, maintain, or decrease their interest in science research over time.

Abbreviations

STEM: Science, technology, engineering, and mathematics; ISE: Informal science education.

Supplementary Information

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Additional file 1. Authentic STEM research, practices of science, and interest development in an informal science education program: methods supplement and Figures S1–S21.

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Authors' contributions

The authors conceived, designed, and wrote the manuscript for this study. Both authors read and approved the final manuscript.

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Availability of data and materials

The data and materials used in the current study are available from the corresponding author upon request.

Declarations

Competing interests

The authors declare no competing interests.

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