Journal for STEM Education Research
https://doi.org/10.1007/s41979-024-00117-0

RESEARCH BRIEF

Computational Thinking During a Short, Authentic, Interdisciplinary STEM Experience for Elementary Students

Jessica F. Cantlon[1,3] · **Katherine T. Becker**[2] · **Caroline M. DeLong**[2,3]

Accepted: 27 February 2024

Abstract
STEM experiences that capture students' curiosity have a unique role in inspiring awe in science, enculturing science engagement, and recruiting students to pursue STEM careers. Here, we present a unique interdisciplinary STEM experience for elementary school students that teaches them to write computer code to test primate intelligence at a zoo where they test their code with real monkeys. In a pilot study involving 3rd to 6th grade students, we find that students can acquire "hard skills" in computational thinking during this short-term immersive STEM experience, with a significant increase in accuracy and problem-solving attempts at post-test. Furthermore, students' interests in animal science, computers, and robots remain stable or even increase following this experience, demonstrating the project's capacity to blend technical skills with authentic scientific exploration. Teachers' feedback highlights the positive impact on critical thinking and leadership. This research underscores the potential of free-form, authentic, interdisciplinary STEM experiences to simultaneously nurture computational skills and a passion for science.

Keywords K12 · Integrated learning · Coding · Animal behavior · Non-formal learning · Informal learning · Computational thinking · Immersive · STEM interest

Introduction

In the USA, completion rates for STEM degrees are relatively low, with computer science having the lowest rate (Nite et al., 2020). However, computer science skills are increasingly valuable across many career fields, including the social and life

✉ Jessica F. Cantlon
jcantlon@andrew.cmu.edu

1 Psychology Department, Carnegie Mellon University, Baker Hall 327M, Pittsburgh, PA 14627, USA

2 Department of Psychology, Rochester Institute of Technology, Rochester, NY, USA

3 Seneca Park Zoo, Rochester, NY, USA

Published online: 02 April 2024

sciences, prompting educational initiatives that integrate computer science education within traditional STEM disciplines (National Research Council, 2009). The integration of computational skills into STEM education is a relatively new concept for K-12 educators and a current focus for educational researchers (Li et al., 2020; Yang et al., 2021).

A central concern of educators, researchers, and policymakers is how to help students keep pace with the challenging technical demands of twenty-first-century science while maintaining a high interest in STEM (Gardner et al., 2022; LePendu et al., 2020; National Science Board, 2010; Next Generation Science Standards, 2013; Nite et al., 2020). One skill that the education community has identified as a critical one for twenty-first-century STEM learning is computational thinking. Computational thinking is systematic problem-solving using a set of rules or procedures (Wing, 2006). It is the ability to think about complex problems using logical step-by-step solutions that are algorithmic and generalizable. Educators widely agree that computational thinking is critical for success in a broad range of academic disciplines, particularly STEM subjects and that interventions must enter the curriculum early, during elementary school (e.g., Resnick, et al., 2009; Yang et al., 2021). But, currently, there is no consensus on *how* computational thinking is best integrated into elementary school curricula.

A second concern of educators is that students lose interest in STEM subjects because they perceive the science they learn in the classroom as an abstraction that is disconnected from the real world and is, therefore, boring (Braund & Reiss, 2006). Schools sometimes complement classroom curricula with out-of-school field trips but those activities, like visiting labs, conservatories, or museums, sometimes lack the critical ingredients of doing science—which are creativity, problem-solving, and discovery (Stocklmayer et al., 2010). To address this problem, the education community has called for more informal, non-formal, hands-on, and immersive educational opportunities that complement formal STEM instruction—opportunities that take students out of the classroom and let them participate in scientific research in action (Gardner et al., 2022; National Research Council, 2010, 2015; Yang et al., 2021).

Informal and authentic STEM activities, which challenge students to use scientific tools in a real research environment, have an important place in STEM education which is to excite students, activate their agency, and strengthen their understanding of real-world science (e.g., Braund & Reiss, 2006; Gardner et al., 2022; Hurst et al., 2019). Research shows that early authentic experiences with scientific research engage and sustain students' interests in science (Habig & Gupta, 2021) and promote fascination with science (Bonnette et al., 2019). These experiences are important early in development because early informal STEM experiences are associated with higher and more sustained STEM achievement (Hurst et al., 2019).

Authentic STEM activities also reveal to students the true, interdisciplinary nature of modern science. When scientists in the social and life sciences engage in real research, they generate their own research questions while also using computational methods, such as computer programming, data visualization, and statistics. But while modern science demands the integration of STEM skills and knowledge, STEM skills are typically taught as separate subjects during elementary, middle, and high school (e.g., biology, computer science, and statistics). Often, college is the first time that students are asked to apply interdisciplinary skills, and this transition is a difficult one for them (e.g., Ryder et al., 1999). However, immersive and inquiry-based activities that require interdisciplinary learning are gaining prominence in middle and high school settings and are increasingly being introduced in elementary schools (NGSS Lead States, 2013). Many inventive educators and scientists are creating new immersive STEM experiences for elementary, middle, and high school students (e.g., Aloisio et al., 2018; Barros-Smith et al., 2012; Buxton, 2006; Habig & Gupta, 2021; Habig et al., 2020; Miller et al., 2011; Ward et al., 2012; Weiss & Chi, 2019).

One barrier to integrating informal and non-formal scientific research experiences in elementary schools is that there are few data showing skill acquisition during these types of experiences (Gardner et al., 2022). Evidence-based research on informal education outcomes in K-6 computer science is only just emerging as a field (Gardner et al., 2022). Quantitative evaluations of the impact of informal computer science experiences on elementary school students' learning outcomes are especially rare (Gardner et al., 2022; NRC, 2010; 2015). Thus, it is difficult for educators and researchers to determine what types of out-of-school STEM experiences are productive. Moreover, there are currently few data on the connection between out-of-school science experiences and the acquisition of formal knowledge, such as computational thinking. This void reduces certainty that an out-of-school science experience could foster growth in the "hard skills" that educators must teach while also generating curiosity and fascination for science.

The proof-of-concept question we ask is as follows: Is it possible to get students to learn effortful "hard skills" in computational thinking during a short-term authentic STEM experience while also maintaining their interest in the science? We describe pilot data that address this question from an authentic interdisciplinary psychology, evolutionary biology, and computer science research experience with 3rd to 6th-grade students.

Objectives and Audience

Our STEM education project seeks to establish a bridge between animal research and computer programming. By capitalizing on students' robust fascination with animals and particularly "charismatic mega-fauna," we aim to kindle a parallel interest in coding. Coding holds a high allure for male students, but its appeal is comparatively modest among girls and minority students (Cheryan et al., 2017; Master et al., 2016; Master et al., 2021). Since interest, belonging, and self-efficacy in animal science are high among all gender and minority groups, animal science could provide a gateway connection to computer science for these students (e.g., Baram-Tsabari et al., 2006; Mueller et al., 2018). And, since fascination with "animals," is a unifying scientific interest among all students, irrespective of background, this animal-focused coding project could serve as a compelling experience to spark curiosity in science for everyone. This general design of using authentic animal science, as leverage to develop "hard skills" in science, could be applied more broadly in science and technology curricula to engage more diverse students in STEM, beginning in elementary school.

Learning Environment, Community, and Resources

During our project-based curriculum, elementary school students in 3rd to 6th grades design computer code using the block-coding language *Scratch* (MIT Media Lab) to test the intelligence of primates who are trained to use touchscreen computers to perform cognitive tasks at the Seneca Park Zoo in Rochester, NY.

The project uses “The Primate Portal” exhibit—an animal cognition exhibit designed by Dr. Jessica Cantlon (Carnegie Mellon University), Dr. Caroline DeLong (RIT), and the Seneca Park Zoo in Rochester, NY (Fig. 1). The Primate Portal is a zoo exhibit in which the public can watch olive baboons solve problems presented as computerized tasks on a touchscreen computer. Scientists conduct cognitive studies with these monkeys as part of an Institutional Animal Care and Use Committee (IACUC) approved research program. The monkeys are trained to touch images on the computer screen in exchange for cereal pellets that are automatically dispensed when they make correct responses on the tasks. The tasks that the monkeys are trained to play include many types of matching games (e.g., match an image of a

Fig. 1 The Primate Portal exhibit at the Seneca Park Zoo. Dr. DeLong discusses primate research with assistant researchers Jessica Wegman and Katie Becker (top), while an olive baboon (bottom) uses the touchscreen interface to perform cognitive tasks

flower to another image of a flower, or match a geometric pattern to another similar pattern), and detection games like “Where’s Waldo?”.

We partner with teachers at public and private schools who are planning a module on block coding to develop an assignment in which the students code cognitive “games” for the monkeys—and then the students come to the zoo to watch the monkeys play the games they coded. The games we instruct students to design are simple designs such as picture-matching tasks or target-detection tasks that the monkeys are already good at solving.

Prerequisite Student Knowledge

At the start of the project, we provide teachers with the introductory modules from the Harvard Scratch Curriculum to introduce the core coding concepts students need for our assignment (Brennan et al., 2014). We also walk teachers through example Scratch code from previous students who wrote code for the Primate Portal. Teachers decide, based on students’ existing coding levels, how to administer the introductory content. Typically, 3rd- to 6th-grade students in New York state schools already have some experience with block coding software such as bee bots and other floor robots, Alice, Lightbot, Snap, Code.org, Scratch, and Scratch Jr. Visual block coding for elementary students is part of the Next Generation Science Standards (NGSS, 2013) and the NY State Computer Science and Digital Fluency Learning Standards (NYSDE, 2020). Prior to beginning our project, teachers typically administer one to three lessons in Scratch to familiarize students with its basic syntax. An introduction to Scratch basics is sufficient to program a simple game.

Learning Content and Time

Our project-based curriculum unfolds over the course of three- to five-45-min classroom sessions plus one field trip to the zoo. Scientists introduce the project idea to students as an opportunity to make learning games for monkeys at the zoo that test how the monkeys think and are enriching for them. Teachers also introduce the Scratch software basics and ensure that students have prerequisite knowledge. Scientists from the Primate Portal deliver an initial buy-in session and a second scientific lecture. The buy-in session is an interdisciplinary class on animal cognition, evolution, data, coding, and a Q&A session with our research team. The lecture includes dynamic activities like “Are you as smart as a monkey?” where students try to discover, by trial-and-error, rules to tasks that monkeys are good at solving. During the buy-in session, scientists from our team explain to students how we use computer coding as a tool to conduct experiments and analyze data from animals. The scientists show videos of animals doing cognitive tasks and students are asked to reflect on what the animals have to “know” to solve the game. Students see examples of code that previous students wrote for the monkeys, and they are walked through a graph of animal accuracy data and asked to interpret slopes (compare three monkeys’ slopes and report who learned the fastest) and data density (compare three monkeys' scatter plots and report who is the hardest working, i.e., has the most data). Finally, our team is an all-woman team, and we highlight our identities to illustrate that women are scientists. Figure 2 shows excerpts from the buy-in session of the project. The duration of the buy-in session ranges from 60 to 180 min. In the second classroom, session scientists present students with information about science and science-related careers to help them connect the content of our project to ideas about their future.

Once students are familiar with the fundamentals of *Scratch*, they begin their free-form coding assignment. Students work as a group, and with teachers and scientists to decide what kind of game they will code for the monkeys. Then, students author their own coding project in an interactive environment. They work freely and interactively with their peers and teachers to code their own versions of that game for the monkeys. Thus, while each student authors their own code, they can ask their peers and teachers for advice and ideas. Students have the freedom to choose many parameters of the game they code—they choose the images, sound effects, feedback, and backgrounds. They also choose their own algorithms for writing successful code. There are multiple scripts and techniques for

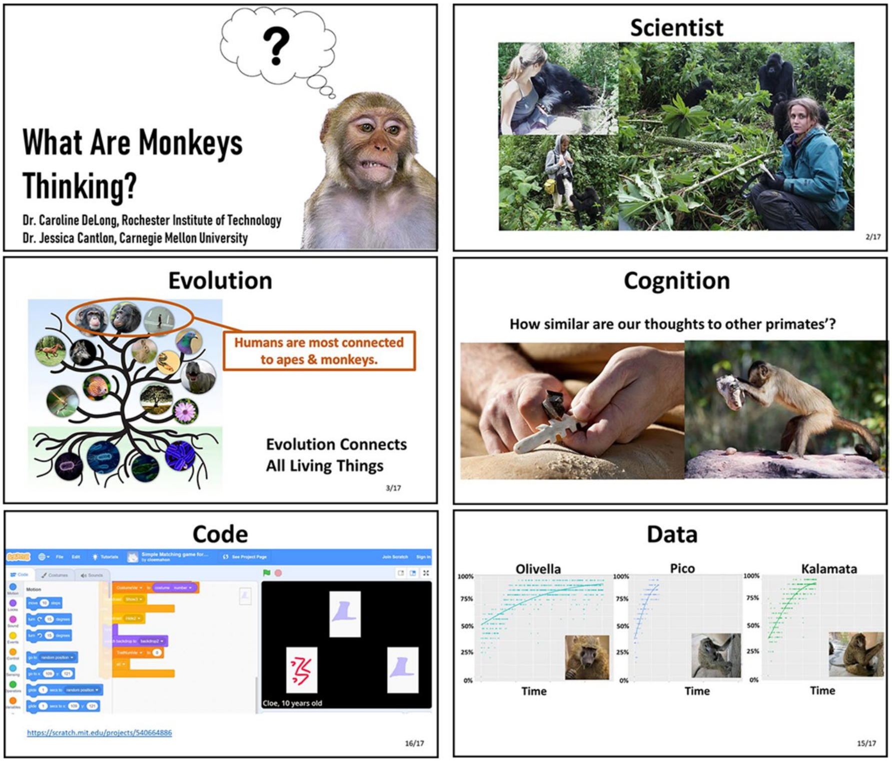

Fig. 2 Example slides from the scientific lectures for elementary school students by Dr. Cantlon and Dr. DeLong. Lecture content includes animal cognition, scientist identities, evolution, psychology, coding, and data interpretation

accomplishing successful code and students can decide their own coding approach. Students work out their coding approach during collaborative class sessions where they can ask teachers and peers for advice, troubleshoot their code, and show off their coding accomplishments. Classroom teachers who are experienced with computer science oversee the student coding sessions and dynamically guide students to make good choices in their Scratch coding techniques. The time that students commit to coding varies based on the complexity of the approach they chose, the number and types of bugs they encounter, and their skill. However, all students have completed the code for the project within 3–5 class sessions. Collectively, the approach occupies about 4–8 class sessions.

After students complete their coding projects, the scientists translate students' Scratch code into JavaScript and test it for bugs on the Primate Portal hardware. Only minor edits were made to students' code in this translation process.

Once all students' scripts are functioning on the hardware, students visit the zoo on a class field trip to watch the monkeys interact with the games that the students coded. This is a free-form science experience where scientists show students how the Primate Portal hardware works, load the students' code for the monkeys to play, and then scientists and students dynamically interact to discuss how the monkeys are behaving with the games. Students ask questions about code, hardware, animal psychology, biology, and the zoo, among other topics.

Students are often fascinated by seeing their code operate on the Primate Portal hardware. During the students' visit, scientists describe the hardware at the Primate Portal which involves a computer that renders the students' code on an automated touchscreen and an automated cereal-dispensing machine for the monkeys—a kind of "robot." Students learn how their code appears on the monkeys' touchscreen, they learn that the machine they programmed is recording the monkeys' touches and that it robotically feeds cereal pellets to the monkeys only for responses that the students coded as "correct" in their game. Students are even invited to eat one of the monkeys' cereal pellets if interested. Thus, the project exposes students to coding as well as its implementation in machines and robotic hardware.

Learning Objectives

The overall project is an informal STEM learning experience that exposes students to authentic, interdisciplinary scientific research with real animals while building their coding skills. The free-form and free-choice dimension of the experience is designed to raise student voices and foster independence, discovery, and enjoyment of scientific work. These learning goals are assessed with student and teacher self-report surveys. The coding assignment is a problem-solving project meant to expand students' computational thinking skills. It requires systematic problem-solving to create a logical step-by-step computer program within the Scratch syntax. This learning goal is assessed with a computational thinking test.

Learner Characteristics

Fifty-seven 3rd- to 6th-grade students from three schools in Western New York successfully completed code for the Primate Portal project as part of their in-class STEM work. The participating schools were Allendale Columbia School in Brighton, NY, QUEST Elementary in Hilton, NY, and Brooks Hill Elementary in Fairport, NY. We collected data on students from two public school classrooms. One was a 3rd-grade classroom from Brooks Hill Elementary ($N = 18$, 44% female; mean age = 8.39 years), and the second was a mixed 5–6th-grade gifted classroom from QUEST Elementary ($N = 20$, 40% female, 5% non-binary; mean age = 10.9 years). Both classrooms had specialist educators in computing and digital literacy. The 3rd-grade classroom completed the project as part of their normal learning time, and the 5–6th-grade classroom completed the project during an in-school breakout block (REACH gifted/talented program). We did not collect data on SES, race, or ethnicity, but the school demographics are 25% free lunch eligible, 20% minority students at Brooks Hill, and 18% free lunch eligible, 13% minority students at QUEST Elementary.

Data Types

We collected pre- and post-project data from $N = 38$ students (3rd to 6th grade; mean age = 9.7 years, SD = 1.45). The students were from two public schools near Rochester, NY: QUEST Elementary and Brooks Hill Elementary. The data included (A) a quantitative computational thinking assessment designed by education researchers at *Everyday Computing* (Gane et al., 2021), (B) a quantitative STEM interest survey, and (C) a survey about student learning and enjoyment. We also collected (D) qualitative teacher experience data chronicling their observations of students during the project and teachers' interest and enjoyment of the project.

A. Computational Thinking Assessment

To measure students' acquisition of concrete computational skills, we administered a computational thinking assessment designed by researchers at Everyday Computing (Gane et al., 2021). This is a brief paper-and-pencil test designed to test key logical and computational skills that children acquire while learning to code. There are early, mid-, and late versions of the test designed to match the coding skills that children acquire over time. As shown in Fig. 3, we used the early and mid-assessments. The test comes with significant resources for administering the test and scoring students' responses including exemplar responses. Most of the items are scored straightforwardly as correct or incorrect. The test has been validated in one large-scale study with 3rd and 4th-grade students ($N = 144$), although it is still being tested in schools.

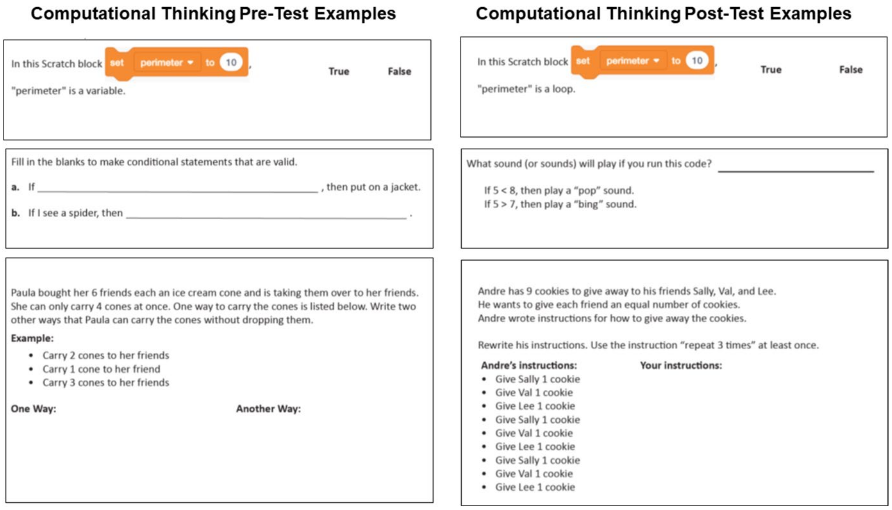

Fig. 3 Example questions from the computational thinking pre-test (left) and post-test (right) designed by researchers at *Everyday Computing* (Gane et al., 2021)

B. STEM Interest Survey

We administered a pre- and post-project STEM interest survey of student's interests in science topics that included the topics targeted by our project (animals, computers, robots, machines) as well as ten other age-appropriate topics (space, the brain, chemistry, the environment, dinosaurs, plants, medicine and health, rockets, rocks and minerals, weather) and the option to select "none." We also included an option for students to write on a science topic that was interesting to them. The instructions for this survey said, "Check 5 things that you are most interested in learning more about." The survey also included questions about students' career goals, self-efficacy, and overall interest in science based on previous research that used these types of questions (Cook et al., 2012; Eccles et al., 1993; Jacobs et al., 2002; Master et al., 2016; Simpkins et al., 2006).

C. Student Project Experience Survey

At the end of the project, students completed a second survey about their experience with the project. They were asked questions: "Did you enjoy learning about animal thinking and baboons? Circle Yes/No," "Tell me something you learned," "Did you enjoy learning about computer coding? Circle One: Yes/No," and "What was the coolest thing you learned?" Students also had the opportunity to describe what they did not enjoy in question, "When we do this project next year with a new group of kids, what should we do differently?".

D. Teacher Project Experience Survey

At the end of the project, teachers completed an open-ended survey about their views of the project. It included questions such as "Did you enjoy this unit? What was the process like from your point of view?" and "Did your students have a positive experience? Did some of them really shine? Was the challenge of learning to code productive even for students who struggled?".

Data collection for the pre-test occurred during the class session prior to the day students began their primate coding assignment, and the post-test data were collected in the class session after they completed their code (approximately 4 weeks between the pre- and post-test). All data were collected within a 1-month period, and thus pre- and post-testing occurred on a short-time scale in close proximity to our project assignment. All students completed the STEM Interest and Project Experience pre- and post-surveys, and the QUEST Elementary students additionally completed the Computational Thinking pre- and post-tests.

All students in this sample authored an individual coding project, although they often talked to teachers and peers for advice. Students' projects were assessed by teachers for functionality and were not given a numeric or letter grade—teachers and peers evaluated the functionality of the code by trying out the code and giving its author real-time feedback. Authors debugged any dysfunctional code until it was functional. All students contributed functional code by the end of the project.

Evidence of Student Learning

The focus of this pilot study is whether, in principle, students can acquire skills in computational thinking during a relatively short, loose format, authentic science experience while also maintaining or gaining excitement over the project's unique immersive experience in animal science. First, we compared 5 to 6th-grade students' pre- and post-test scores on the computational thinking assessment ($N = 19$). If students gained computational thinking skills during the Primate Portal project, we should see an increase in their accuracy on the computational thinking post-test relative to the pre-test. Students' computational thinking scores improved by 17% from the pre-test to the post-test. Boys and girls showed equivalent improvement at post-test (boys = 16%; girls = 18%). A paired t-test between students' pre-test and post-test scores was significant (mean pre-test: 45%, mean post-test: 62%, $t(17) = 3.96$, $p = 0.001$), showing that students' scores improved significantly. Students also attempted more problems on the post-test compared to the pre-test, even though the post-test was more difficult than the pre-test by design (Gane et al., 2021; mean increase: 10%; $t(17) = 3.20$, $p = 0.003$). Figure 4 shows the distribution of students' computational thinking test scores at pre- and post-test. The data indicate that students acquired computational skills during the Primate Portal project.

Secondly, at the beginning and end of the project, we asked students to report their top 5 science interests from a list of 14 options. We measured whether students maintained an interest in the STEM topics at the core of our project,

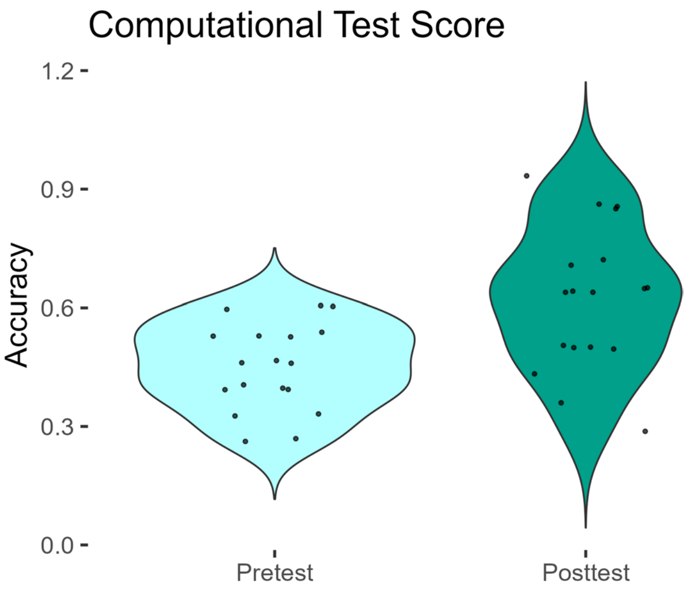

Fig. 4 Accuracy distributions for students' scores on the computational thinking pre-test and post-test. Students' scores significantly improved on the post-test, which was a more difficult test than the pre-test

namely "animals," "computers," and "robots" while also gaining the concrete computational skills they learned during the project. Figure 5 shows how each topic ranked in interest across the group of students at pre-test (left panel) and post-test (right panel). Before the Primate Portal project, "space" ranked the highest among students, followed by "animals," "machines," "computers," and "the brain." After the Primate Portal project, "animals" ranked the highest followed by "robots," "machines," and "space." Thus, there was a slight shuffling of students' science interests after the Primate Portal project, with "animals" and "robots" gaining slightly.

Fisher's exact tests indicated that students' science interests were relatively stable pre- and post-project. Figure 6 shows that students' interests in animals, computers, and robots were maintained as they learned the rigorous and challenging computational skills of the project (odds ratio range = 1.0 to 2.4; all p's > 0.30). Taken together with students' computational thinking scores, this result means that it is possible to keep, or even increase, elementary students' interests in animal science while teaching them challenging technical computer science skills during a short, informal STEM experience.

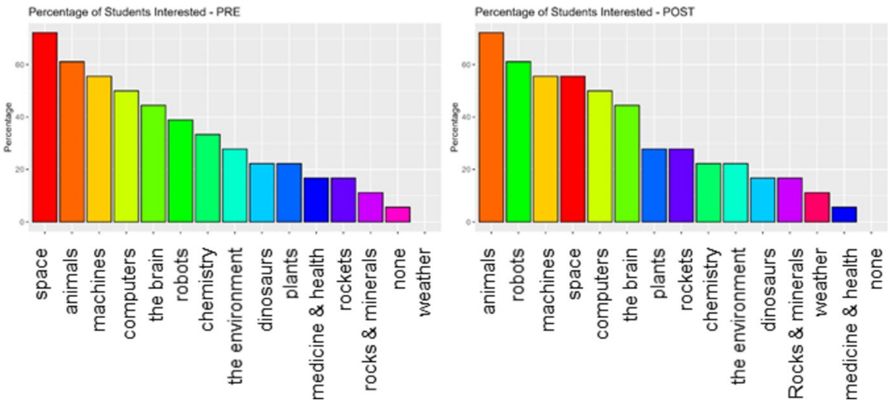

Fig. 5 Percentage of students who rated each of 14 topics as one of their top five science interests during the pre-test (left) and post-test (right). The rainbow color ranking reflects the ranking of each topic at pre-test. The ranking of categories changed between pre-test and post-test with notable gains in "animals" and "robots"

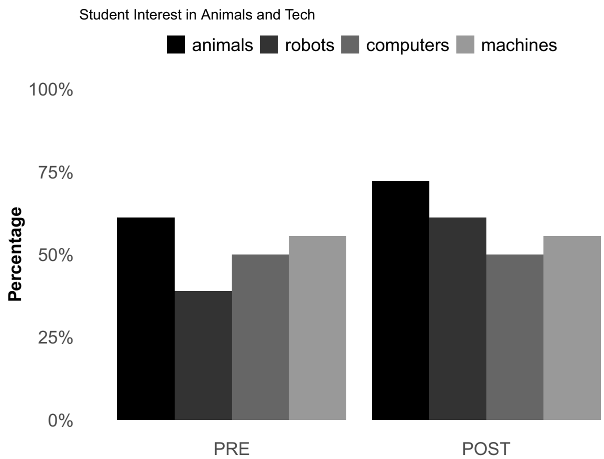

Fig. 6 Students' interests in "animals" and technology domains were stable between pre-test and pos-test and showed a trend toward increasing slightly

Finally, after submitting their project code and visiting the zoo exhibit on a field trip, 3rd to 6th-grade students and their teachers completed a survey about their experiences with the project. At the beginning of the project, there was a gap between interest in animals and interest in computers—students were more interested in animals than computers (Fig. 7; Fisher's exact test; $N=36$; odds ratio $=0.18$; $p=0.05$). However, at the conclusion of the project, there was no difference in students' enjoyment of learning about animals versus computer coding (Fig. 7; Fisher's exact test: $p=1$). Students enjoyed learning about animal behavior and computer coding equally. Moreover, at pre-test and consistent with prior

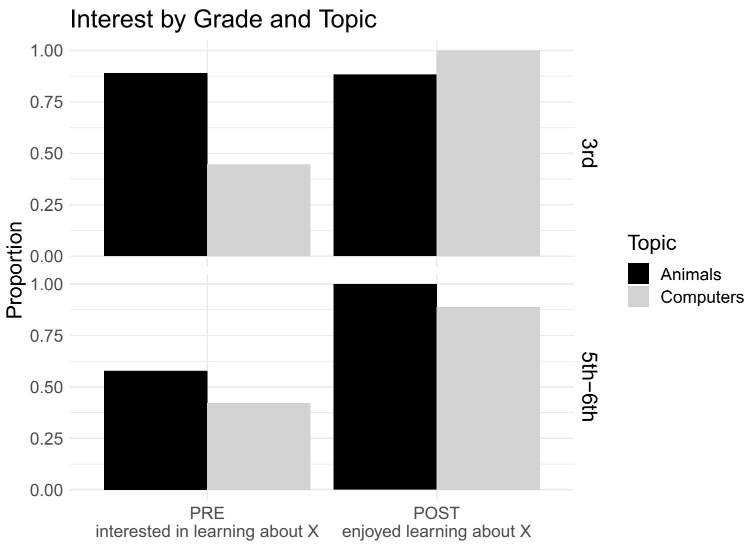

Fig. 7 Students showed a significant difference in interest between "animals" and "computers" at pre-test but showed equal and high enjoyment of learning about "animals" and "computers" at post-test

research, boys were more likely than girls to list "computers" as an interest (51% vs 20%). At the post-test, however, there was no gender gap in students reporting enjoyment of learning about computers (boys = 100%; girls = 94%; Fisher's exact test: $p = 1$).

We asked students to report something that they learned during the Primate Portal project. Students' responses are shown in Table 1. Responses included a relatively equal mix of statements about animal science and computer science. Many students described something specific that they learned such as, "The coolest thing I learned was how to use the "if then ____ else" block," "I learned that baboons are super smart, as smart as a 2nd grader," and "I learned that their scientific name is *Papio anubis*." Their comments reflect the interdisciplinary nature of the experience and show that students encoded details of the project.

Teachers' feedback was positive, emphasizing the constructive challenges and students' newfound independence. For instance, a 3rd-grade teacher said, "This unit allowed our students to critically think, learn from their mistakes, and stretch their thinking. It was engaging and rewarding." They noted, "There are other varying needs in our classroom. Despite this, every student was able to complete a project. A student who really was able to shine was a student who has an IEP (*Individualized Education Plan*). She loved that she was able to manipulate the code to meet the requirements. She was able to be a leader in the classroom and was amazing to watch!" In a similar vein, a 5–6th-grade teacher reported, "It appeared productive for all as they all successfully coded a program that worked." All teachers were eager to return to the project in the next academic year with a new, expanded cohort of students.

Table 1 All students' responses to learning query

Tell me something you learned. What's the coolest thing you learned?
I learned that when they get the games right, they get candy
The thing I got to learn is that baboons can do math! (they are super intelligent)
I learned that baboons are primates and highly intelligent
I learned that baboons are super smart, as smart as a 2nd grader
I learned that baboons are as smart as a 2nd grader
I learned that baboons can play mini games
I learned that baboons are just like us
One thing I learned is that "Maybe So (circled)"
I learned that baboons play games and get candy
I learned that coding was very fun
I learned that primates are intelligent
I learned about the baboons was that they are the most animals that look like humans
I learned that the baboons are smarter than they look!
How to code so baboons can play it smoothly
I learned that you can't have a long wait or the baboons will get bored
I learned that some baboons are smarter than others
I learned that they are smart and they can play games
How to code games
I enjoyed playing the games
The coolest thing I learned was how to make a mini game
The coolest thing I learned was how to code very hard codes
The coolest thing I learned was that baboons are as smart as a 2nd grader
The coolest thing I learned was how to change a backdrop to another backdrop
The coolest thing I learned was that you can make a sprite move
The coolest thing I learned was how to write my name and the sounds
I already learned how to code
All of it
The coolest thing I learned was how to change the background when they finished
I enjoyed when we coded the monkeys project
I learned how to code games on Scratch
The coolest thing I learned was that I learned how to code when I didn't know how
How to code intcheelx
The coolest thing I learned was how to use the "if then else" block
All of it because now I can make my own game
The coolest thing I learned was coding
The coolest thing I learned is that baboons are as smart as a seventh grader
How to code
How to code on Scratch
The zoo baboons name, and how they act
About dominant baboons and they can groom baboons to climb the ranks

Table 1 (continued)

Tell me something you learned. What's the coolest thing you learned?
How to code for the primate portal
I learned that baboons are smarter than I thought
I learned a lot about coding and olive baboons
That baboons are a lot like humans
The baboons are about as smart as a 2 year old
I learned that their scientific name is *Papio anubis*
They can see the same amount of colors we see!
Some baboons are smarter than other
I learned that humans have the same process as baboons
Baboons live in big groups
I learned that baboons are almost as smart as humans when problems were easy and difficult, but in the middle, they did not do good
I learned a lot about coding. For example, I got to learn the difference between a sprite and a character
I learned many things. For example: How baboons become dominant
How to make my own [] on Scratch
The code and how it works
How to make things like Flappy Bird
About how to use variables and what you can do with Scratch
That some variables can make the sprites change shape and color
How to use Scratch
The coolest thing I learned is that you can make your own game on Scratch
The coolest thing I learned was we evolved from animals. I had a hard time with coding
That there is block coding
I learned how to code on Scratch
I learned that coding had variables, and they do different things
That you can make costumes for a sprite
Everything
I learned how to think mechanically
Learning to change things on Scratch
Being able to see my game be played by baboons
That you can make a sprite go to a random place
I learned how to use Scratch; some things I learned about: Sprite movement, variables, and how to make it work

Conclusion

The Primate Portal project combines "learning and doing" in STEM—it integrates pedagogy on computational skills, authentic animal cognition research experience, an encounter with scientists, and a field trip to the zoo. The goal of the project is to provide an impactful, episodic STEM experience that makes science memorable for students while also developing their hard skills in computer programming and interdisciplinary knowledge of real-world science. The results of the pilot study show that, in principle, it is possible for students to acquire "hard skills" in computation while also benefitting from the authentic and immersive elements of the science experience. The project thus illustrates how "learning and doing" can be integrated to teach students to use scientifically appropriate knowledge and tools, even in elementary school (Bybee, 2011).

Data on the impact of informal, immersive, and authentic STEM experiences are rare because it is difficult to identify and administer relevant assessments during complex, short-term STEM experiences (NRC, 2010). We focused our curriculum and assessment on computational thinking because the NGSS recognized computational thinking as a key scientific practice (NGSS Lead States, 2013), and the National Science Board (2010) has supported teaching computational thinking in elementary school. However, according to the National Research Council (2010), assessing individual performance after an informal learning intervention often underestimates the success of the intervention because it is difficult to capture the social, collaborative, and problem-solving knowledge that is gained from the experience. These findings suggest that despite our observations of improved computational ability in the students we tested, any assessment could underestimate the value and impact of the Primate Portal learning experience. Indeed, qualitative comments from students and teachers about the project indicated that the project impacted unique types of learning, such as creativity and independence, which are difficult to measure.

Beyond its technical merits, the Primate Portal project exhibits a successful community education partnership between teachers, scientists, a county zoo, and students. Such partnerships provide unique opportunities to bring real-world research inquiry into the classroom. Engaging experiences that align with students' natural interests, even when they involve demanding STEM skills that students find taxing, hold the potential to counteract the waning enthusiasm often observed in STEM subjects during late elementary and middle school years. Previous research has shown that when the connections between STEM content and children's own experiences and interests are made explicit, it facilitates their comprehension, information retention, and long-term learning (Hurst et al., 2019; Ornstein et al., 2004; Valle & Callanan, 2006). Our findings from this pilot study are consistent with those past findings in the sense that bridging students' curiosity about the real world with challenging computational learning could likewise enhance their interest in science and cultivate essential twenty-first-century skills.

Acknowledgements We thank the teachers: Greg Booth, Travis Wood, Theresa Sanna, and Susan Layton for participating in this project. We thank the Seneca Park Zoo: Keepers Clare Belden, Jenna Bovee, Linda Velasquez, Maggie Kinsella, Assistant Curator Lindsay Brinda, Superintendent Steve Lacy, and General Curator David Hamilton. We thank the students at Allendale Columbia School, QUEST Elementary, and Brooks Hill Elementary – and their principals or directors, Derek Warren, Shannon Baudo, and Meredith Klus for welcoming us into their school. We thank Hugo Angulo for technical innovation and support, and Jessica Wegman for assistance with the Primate Portal exhibit. This work was supported by the National Science Foundation NSF2148343 and the Ronald and Mary Ann Zdrojkowski Chair in Developmental Neuroscience.

Funding Open Access funding provided by Carnegie Mellon University

Data Availability All materials and anonymized data are available on request.

References

Adams, J. D., Gupta, P., & DeFelice, A. (2012). Schools and informal science settings: Collaborate, co-exist, or assimilate? *Cultural Studies of Science Education, 7*, 409–416.

Aloisio, J. M., Johnson, B., Lewis, J. D., Alan Clark, J., Munshi-South, J., Roberts, S. J., & Tingley, K. (2018). Pre-college urban ecology research mentoring: Promoting broader participation in the field of ecology for an urban future. *Journal of Urban Ecology, 4*, 1.

Baram-Tsabari, A., Sethi, R. J., Bry, L., & Yarden, A. (2006). Using questions sent to an Ask-A-Scientist site to identify children's interests in science. *Science Education, 90*(6), 1050–1072.

Barros-Smith, R., Porro, I., & Norland, E. (2012). Developing teenage youth's science identity through an astronomy apprenticeship: Summative evaluation results. *Astronomical Society of the Pacific Conference Series, 457*, 209–212.

Bonnette, R. N., Crowley, K., & Schunn, C. D. (2019). Falling in love and staying in love with science: Ongoing informal science experiences support fascination for all children. *International Journal of Science Education, 41*(12), 1626–1643.

Braund, M., & Reiss, M. (2006). Towards a more authentic science curriculum: The contribution of out-of-school learning. *International Journal of Science Education, 28*(12), 1373–1388.

Brennan, K., Balch, C., & Chung, M. (2014). Creative computing. Retrieved from http://scratched.gse.harvard.edu/. Accessed 6/1/2023.

Buxton, C. A. (2006). Creating contextually authentic science in a "low performing" urban elementary school. *Journal of Research in Science Teaching, 43*(7), 695–721.

Bybee, R. W. (2011). Scientific and engineering practices in K-12 classrooms: Understanding a framework for K-12 science education. *The Science Teacher, 78*(9), 34.

Cheryan, S., Ziegler, S. A., Montoya, A. K., & Jiang, L. (2017). Why are some STEM fields more gender balanced than others? *Psychological Bulletin, 143*(1), 1.

Cook, J. E., Purdie-Vaughns, V., Garcia, J., & Cohen, G. L. (2012). Chronic threat and contingent belonging: Protective benefits of values affirmation on identity development. *Journal of Personality and Social Psychology, 102*, 479–496.

Eccles, J., Wigfield, A., Harold, R. D., & Blumenfeld, P. (1993). Age and gender differences in children's self-and task perceptions during elementary school. *Child Development, 64*(3), 830–847.

Gane, B. D., Israel, M., Elagha, N., Yan, W., Luo, F., & Pellegrino, J. W. (2021). Design and validation of learning trajectory-based assessments for computational thinking in upper elementary grades. *Computer Science Education, 31*(2), 141–168.

Gardner, T., Leonard, H. C., Waite, J., & Sentance, S. (2022). What do we know about computing education for K-12 in non-formal settings? A systematic literature review of recent research. *In Proceedings of the 2022 ACM Conference on International Computing Education Research, 1*, 264–281.

Habig, B., & Gupta, P. (2021). Authentic STEM research, practices of science, and interest development in an informal science education program. *International Journal of STEM Education, 8*, 1–18.

Habig, B., Gupta, P., Levine, B., & Adams, J. (2020). An informal science education program's impact on STEM major and STEM career outcomes. *Research in Science Education, 50*, 1051–1074.

Hurst, M. A., Polinsky, N., Haden, C. A., Levine, S. C., & Uttal, D. H. (2019). Leveraging research on informal learning to inform policy on promoting early STEM. *Social Policy Report, 32*(3), 1–33.

Jacobs, J. E., Lanza, S., Osgood, D. W., Eccles, J. S., & Wigfield, A. (2002). Changes in children's self-competence and values: Gender and domain differences across grades one through twelve. *Child Development, 73*(2), 509–527.

LePendu, P., Cheung, C., Salloum, M., Sheffler, P., & Downey, K. (2020). Summer coding camp as a gateway to STEM. In *SIGCSE '20: Proceedings of the 51st ACM Technical Symposium on Computer Science Education* (pp. 1351). https://doi.org/10.1145/3328778.3372637

Li, Y., Schoenfeld, A. H., diSessa, A. A., Graesser, A. C., Benson, L. C., English, L. D., & Duschl, R. A. (2020). On computational thinking and STEM education. *Journal for STEM Education Research, 3*, 147–166.

Master, A., Cheryan, S., & Meltzoff, A. N. (2016). Computing whether she belongs: Stereotypes undermine girls' interest and sense of belonging in computer science. *Journal of Educational Psychology, 108*(3), 424.

Master, A., Meltzoff, A. N., & Cheryan, S. (2021). Gender stereotypes about interests start early and cause gender disparities in computer science and engineering. *Proceedings of the National Academy of Sciences, 118*(48), e2100030118.

Miller, J. L., Ward, R. B., Sienkiewicz, F., & Antonucci, P. (2011). ITEAMS: An out-of-school time project to promote gain in fundamental science content and enhance interest in STEM careers for middle school students. *Journal of Systemics, Cybernetics and Informatics, 9*(4), 76–80.

Mueller, M., Byrnes, E., Buczek, D., Linder, D., Freeman, L. & Webster, C. (2018). Engagement in science and engineering through animal-based curricula. *Journal of STEM Education, 18*(5), 10–14.

National Research Council. (2009). *A new biology for the 21st century*. The National Academies Press.

National Research Council. (2010). *Surrounded by science: Learning science in informal environments*. The National Academies Press.

National Research Council. (2015). *Identifying and supporting productive STEM programs in out-of-school settings*. The National Academies Press.

National Science Board. (2010). *Science and engineering indicators 2010*. National Science Foundation (NSB 10–01). https://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsb1001

New York State Department of Education. (2020). New York State K–12 Computer Science and Digital Fluency Learning Standards. Retrieved from: https://www.nysed.gov/curriculum-instruction/computer-science-and-digital-fluency-learning-standards. Accessed 6/1/2023.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. The National Academies Press.

Nite, S. B., Bicer, A., Currens, K. C., & Tejani, R. (2020). Increasing STEM interest through coding with microcontrollers. *IEEE Xplore*. https://doi.org/10.1109/FIE44824.2020.9274273

Ornstein, P. A., Haden, C. A., & Hedrick, A. M. (2004). Learning to remember: Social-communicative exchanges and the development of children's memory skills. *Developmental Review, 24*, 374–395.

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., Millner, A., Rosenbaum, E., Silver, J., Silverman, B., & Kafai, Y. (2009). Scratch: Programming for all. *Communications of the ACM, 52*(11), 60–67.

Ryder, J., Leach, J., & Driver, R. (1999). Undergraduate science students' images of science. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 36*(2), 201–219.

Simpkins, S. D., Davis-Kean, P. E., & Eccles, J. S. (2006). Math and science motivation: A longitudinal examination of the links between choices and beliefs. *Developmental Psychology, 42*(1), 70–83.

Stocklmayer, S. M., Rennie, L. J., & Gilbert, J. K. (2010). The roles of the formal and informal sectors in the provision of effective science education. *Studies in Science Education, 46*(1), 1–44.

Valle, A., & Callanan, M. A. (2006). Similarity comparisons and relational analogies in parent-child conversations about science topics. *Merrill-Palmer Quarterly, 52*(1), 96–124.

Ward, R., Miller, J. L., Sienkiewicz, R., & Antonucci, P. (2012). ITEAMS: Increasing the self-identification for girls and underserved youth in pursuing STEM careers. *Journal of Systemics, Cybernetics & Informatics, 10*(1), 95–99.

Watters, J., & Diezmann, C. (2013). Community partnerships for fostering student interest and engagement in STEM. *Journal of STEM Education, 14*(2), 47–55.

Weiss, E., & Chi, B. (2019). ¡Youth & The Ocean! (¡YO!): Partnering high school and graduate students for youth-driven research experiences. In G. Fauville, D. Payne, M. Marrero, A. Lantz-Andersson, & F. Crouch (Eds.), *Exemplary practices in marine science education* (pp. 27–58). Springer. https://doi.org/10.1007/978-3-319-90778-9_3

Wing, J. M. (2006). Computational thinking. *Communications of the ACM, 49*(3), 33–35.

Yang, D., Baek, Y., Ching, Y. H., Swanson, S., Chittoori, B., & Wang, S. (2021). Infusing computational thinking in an integrated STEM curriculum: User reactions and lessons learned. *European Journal of STEM Education, 6*(1), 4.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.