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Original Paper

~~E~~Making Time to Grow: An Instructional Design Case from Eight in-School and Six Out-of-School Computer-Supported Plant-Growing Projects

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Abstract

During young adolescence, many youth **AQ1** develop strong identities in relation to science, technology, engineering and mathematics with computing (STEM + C). One way to design for student engagement in STEM + C is to create project-based units that leverage students' interests. We created one such unit, called the "smart greenhouse project". Drawing upon eight in-school-time and six out-of-school-time interventions, we present an instructional design case (IDC). In describing the Context, Final Design, Critical Decisions, Design Limitations and Reflections of this IDC, we highlight design considerations and limitations that may generate new understandings for educational designers engaging with this paper. Our main contributions center on modalities of computer coding, hybridity of instructional materials, flexibility of spatial orientations in computer-supported learning environments, near-peer approaches to teaching and mentoring and dispersed models of professional development. We hope to inspire educational designers to (re-)engage young adolescents in STEM + C learning, in ways that equitably foster youths' rightful presence.

Keywords

Educational design
Instructional design case
Identity
Interest
Physical computing
Project-based learning
Rightful presence
Science, Technology, Engineering and Mathematics with Computing (STEM + C)
~~Technology~~
~~Engineering and mathematics with computing (STEM + C)~~
Secondary education
Student engagement

Supplementary Information

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Context

In this instructional AQ2 design case study (IDC; Howard, 2011; Moore et al., 2023) we report on our interdisciplinary team's efforts to (re-)engage young adolescents with learning experiences in science, technology, engineering and mathematics with computing (STEM + C). In sharing our experiences with past educational designs for computer-supported plant growing, we seek to stimulate knowledge building for future designs of our readers. In more technical terms, we hope that our *precedent experiences* can generate *precedent knowledge* for the *reader-designers* of this manuscript (Gray, 2020; Howard, 2011; Moore et al., 2023; for illustrative examples, see Exter et al., 2014, García-Cabrero et al., 2018 or Roman et al., 2024). More practically, through detailing our design's affordances, limitations, and key shifts, we aim to stimulate reflections and connections for readers, in ways that prove generative for refinement of their own designs.

Forgoing typical "research" article formatting (e.g., Introduction, Methods, Results, Discussion), we adapt a structure more suited to the core purpose of an IDC (Moore et al., 2023). We begin by describing the Context for the educational design. Secondly, we describe the Final Design, which is deliberately flexible in nature. Thirdly, we detail some Critical Decisions we made during our design iterations. Fourthly, we note some Design Limitations, both remedied and not-yet-remedied. Finally, we conclude with some synthesizing Reflections on our design journey, with the goal of our past journeys informing the future journeys of fellow educational designers.

Overall, we offer design considerations (Bielaczyc, 2006) as a menu, rather than a checklist. We invite reader-designers to choose considerations they think and feel are most relevant to their own design contexts. In spirit, the educational design resonates with the first part of this manuscript's title, "Making time to grow". That is, while growing as researchers and practitioners, we particularly prioritize sufficient contact and experimental time for young learners to firmly root their understanding, and to encourage branching out confidently and deliberately.

Rationale

Our team conceptualizes young adolescence, approximately ages 10–15, as stage of life where learners form strong interests and identities (Santrock, 2007), including those related to science, technology, engineering and mathematics (STEM; Maltese & Tai, 2010, 2011). Our work situates computing within disciplines of STEM. We consider Computational Thinking Integration Elements (Lee & Malyn-Smith, 2020), especially in science and engineering, including plant biology, soil chemistry, electromagnetism, and engineering design (~~Authors~~Asante et al., 2021a). Partnering with science teachers, in the terms of Kelley and Knowles (2016) we design our *communities of practice* with *science inquiry* foremost, though some teachers and students have their interested more triggered (Hidi & Renninger, 2006) by *engineering design* or *technological literacy*. Though to some extent mathematical thinking is endemic to the educational design, we do not claim to deeply integrate it, nor do have we achieved a truly integrated STEM model (Kelley & Knowles, 2016). In terms of more artistic or aesthetic elements that could turn "STEM" into "STEAM", we tend to instantiate what Bresler (1995) calls *the affective style*, where artistic applications of LED light strips or aesthetics of otherwise decorating greenhouses can serve to create a positive mood and spark creativity.

We remain mindful that access to STEM + C learning opportunities are not equitable with respect to identity markers such as race and ethnicity, gender, socioeconomic class, cultural and linguistic repertoires, (dis)ability, national origin and more (Blikstein, 2018; Cho et al., 2013; Rodriguez & Lehman, 2017; Romero-Hall, 2022). As such, all iterations of our designs, including the "final design", are oriented towards addressing and redressing historicized inequities. We especially regard those most prevalent in our research-practice partnerships, or "long-term, mutualistic collaborations between practitioners and researchers that are organized intentionally to investigate problems of practice" (Vetter et al., 2022, p. 830). Though we are unaware of projects that focus on adolescents or emphasize physical computing with greenhouses, we do learn with some technology design studies (e.g., Birsan et al., 2017).

We work across both in- and out-of-school-time settings, seeking synergies across learning spaces (Bevan et al., 2010). The eight in-school iterations included between 10 to 15 classes of approximately one hour each, whereas the six out-of-school iterations were five-day camps with roughly 25–30 total hours of time-on-learning (see Sect. 1.2 for details). Overall, our work is guided by the Design Questions,

1. How can we design an authentic experience of youth learning how to monitor and automate plant growth, in order to foster young adolescents' (re-)engaging in science, technology, engineering and mathematics with computing (STEM + C)?
2. What resources do we need to provide for adult and youth (co-)instructors, to better foster learners' engagement?

Our Research-Practice Partnerships

Partner-Schools and -Districts

Our work consists of partnerships between Hillside University (HU) and public middle and high schools in the US Northeast. (All institution and participant names are pseudonyms, unless otherwise noted.) In this case the HU team has partnered with schools in Mills City, Harbor City, Rifton and Rivervale. Selected demographics of students in the partner-districts are shown in Table 1.

Table 1

Selected Demographics for Participating Districts, Schools or Classes **AQ3**

	Race and Ethnicity							Additional Demographics				
	Af. Am.	As.	H	M-R, N-H	NA	NH / PI	W	FL NE	ELL	SwD	ED	HN
Harbor City: entire district	30	10	50	5	<2.5	<2.5	15	50	35	25	70	80
Mills City: Central MS	10	5	60	<2.5	<2.5	<2.5	30	60	20	20	45	70
Mills City: Northwest MS	10	5	25	5	<2.5	<2.5	55	40	10	15	35	50
Rifton: South Charter HS	50	5	20	5	<2.5	<2.5	20	70	20	10	60	70
Hillside U: undergrad class	<2.5	20	5	5	<2.5	<2.5	70	*	*	*	*	*

Notes. All numbers are percentages rounded to the nearest 5%, to preserve anonymity. In all cases, descriptive statistics for gender were roughly 49% female, 49% male and 2% non-binary. For multi-year partnerships, the information was averaged. Abbreviations are as follows: *MS* = Middle School; *Af. Am.* = African American; *As.* = Asian; *H* = Hispanic; *M-R, N–H* = Multi-Race, Non-Hispanic; *NA* = Native American; *NH / PI* = Native Hawaiian / Pacific Islander; *W* = white; *FLNE* = First Language Not English; *ELL* = English Language Learner; *SwD* = Students with Disabilities; *ED* = Economically Disadvantaged; *HN* = High Needs (one or more of ELL within the past four years, SwD or ED). * = unknown

Over time, these partnerships have driven multiple grant proposals and awards, including large-scale national grants from the National Science Foundation. Broadly speaking, these awards seek to develop youth interest in STEM + C, especially with youth who are historically underrepresented in STEM fields. Most recently, the projects have leveraged physical computing in particular, seeking to connect more concrete topics like hydroponics with more abstract concepts in computational thinking. Though centered on youth in grades 6–12, some funding supports the pre-service and in-service teachers who work most closely with youth. One concept that has informed our interventions of late is *rightful presence*, or the agency of an individual or group to belong in a given space as a legitimate participant, rather than a "guest" in a "guest–host" dichotomy (~~Authors~~Jackson & Abdus-Sabur, 2024; Calabrese Barton & Tan, 2019; Squire & Darling, 2013). Arising out of scholarship in sociology with immigrant and refugee populations (Squire & Darling, 2013), rightful presence shows promise in STEM fields for empowering youth in co-creation of novel STEM spaces, as opposed to assimilation into settled STEM (~~Authors~~Jackson & Abdus-Sabur, 2024; Calabrese Barton & Tan, 2019).

Participant-Researchers

Beginning with a core expertise in science education, our lab collaborates with scholars in botany, computer science, career development, mentoring, sense of purpose, entrepreneurship, learning sciences, language-learning and more. Within and between each of these fields, our teammates hold titles as described in the following paragraphs.

We begin introducing perhaps the most essential person, the lab manager. He ensured that all teammates had what they needed, where and when they needed it – not only materially, but at times emotionally and symbolically. He left the lab in late summer of 2022. Since then, it has required several persons to fulfill his duties, which are crucial for the educational design we will detail in "Description of the Final Design".

Next are the personnel whose interests substantially shape design and implementation – graduate students (and, by extension, undergraduates and high-school students). For better and worse (see the "Reflections" section), student-researchers have a substantial degree of autonomy in the lab. Though all core concepts are related to learner engagement, if not engagement itself – e.g., interest, identity, relationships with science, affective domains of learning, etc. – at times our longitudinal analyses were limited by shifts in focal constructs.

We conclude with senior personnel, in large part due to their delegation of responsibility to the aforementioned lab members. Alongside the lab manager, a university professor and a postdoctoral research scientist formed what might best be called a triumvirate for providing leadership across scales of time and space. When additional primary investigators (PIs) or co-PIs joined the partnership, it was this triumvirate that adapted to include newcomers. Relationality statements for the three authors of this manuscript are available in the Appendix.

Evolution of the Partnerships

One prelude to a computer-supported plant-growing project took place in early-spring of 2018, as a pilot study on coding in the Python programming language with one teacher in Harbor City (~ 20 students). The Python programming curriculum shifted from general concepts to plant-growing applications, in late-spring of 2018 with two teachers in Mill City (~ 190 students). The project then rapidly expanded across cities, both in- and out-of-school-time, as summarized in Table 2.

Table 2

Summary of Computer-Assisted Plant-Growing Implementations

Location(s)	Month & Year	grade level(s)	# of teachers	# of students	Notes
Mills City (CMS only)	May–June'18	8	2	190	first iteration (post-pilot), with **text**-based code & browser-***in***compatible
Mills City (CMS & NMS)	May–June'19	8	5	380	same hardware & software; roughly doubled number of students & teachers
Rifton	Sep.-Dec.'19	11–12	1	20	same hardware & software; **elective** class
Hillside University	Jan.- May'20	13–16	1 lead + 2 assist	100	first iteration with **block**-based coding & **browser-**based interface; *non*-science majors
Hillside University	Jan.- May'21	13–16	1 lead + 2 assist	100	second iteration with **block**-based coding & **browser-**based interface; *non*-science majors
Mills City (online)	Feb.'21	6–8	5 lead + 5 assist	15	home-based and fully online (due to COVID-19 policies); used a bookcase-like growing apparatus
Mills City (NMS only)	May–June'21	8	2	130	reduced # of students/class (per COVID-19 impact on in-person attendance)
Mills City (camp)	Aug.'21	6–12	2 lead + 1 assist	10	in-person; primarily a training for near-peer teachers and mentors
Mills City (camp)	Feb.'22	6–8	2 lead + 7 assist	30	the seven assistant-teachers were out-of-school trainees or in-school-time alumni
Mills City (CMS & NMS)	May–June'22	8	5 lead + 10 assist	380	return to the previous peak of students & teachers, now with near-peer assistants
Mills City (camp)	Aug.'22	6–12	2 lead + 2 assist	25	increased capacity for training of near-peer teachers and mentors
Mills City (camp)	Feb.'23	6–8	1 lead + 2 assist	40	increased capacity for middle-schoolers, while reducing near-peer commitment
Mills City (CMS & NMS)	May–June'23	8	5	375	middle-school teachers led the project without support from high-schoolers
Mills City (camp)	Aug.'23	6–12	2 lead + 1 assist	40	further increased capacity for training of near-peer teachers and mentors

Note. Each in-school-time intervention lasted approximately 12–15 class-hours. Each out-of-school-time intervention lasted approximately double the hours (i.e., ~ 24–30 contact-hours). Adults were co-teachers who would "lead", and high-schoolers were co-teachers who would "assist"

Description of the Final Design

The final design of the smart greenhouse project aims to expose students, particularly those from groups traditionally underrepresented in STEM/CS education, to computational science ideas and practices. Most of the target students reported having minimal prior coding experiences. As such, this project embeds the learning of computation within the context of designing an automated greenhouse that can monitor environmental conditions and employs interactive computational approaches of physical computing. Students learn how to work with tangible devices (e.g., sensors, micro-controllers) and iteratively test and revise the computer code and the design of the greenhouse, to create optimal growth conditions for their plants. The conscious going back and forth between the virtual and physical worlds helps make computation concrete and provides an authentic experience for students. This could engender deeper interest among students and spark curiosity to extend their learning (Kelley & Knowles, 2016; Sentance et al., 2017). Further, as the culminating task students need to design and carry out their own scientific investigations using their greenhouses. They can start from the questions they are interested in (e.g., do plants need to have constant airflow?), figure out how to use the greenhouses to answer their questions (e.g., setting up two greenhouses, one with two exhaust fans on all the time and the other one without any fans), and design the greenhouses. In addition, this project engages students in creating block-based coding, which is a visual programming approach that uses colored blocks of code that can be dragged and dropped to create programs. Thus, this approach allows students to focus on the underlying logic of programming and to not worry about syntax, which often creates frustrations among novice programmers. Overall, by combining physical computing, project-based learning and block-based coding, the smart greenhouse project creates engaging and meaningful learning experiences of computation to further motivate students and build their confidence in completing STEM tasks.

Curriculum and Materials

The Smart Greenhouse curriculum included seven modules and took approximately two and half weeks, with each daily class lasting about 50 min. Each of the first six modules focuses on one type of the electronic device and how to control it using computer coding. The last module is the culminating project, which engages students in conducting scientific investigations using their integrated knowledge and skills of coding, engineering and plant science. The final modules are summarized in Table 3. Photographs and screenshots related to the final design are shown in Fig. 1.

Table 3

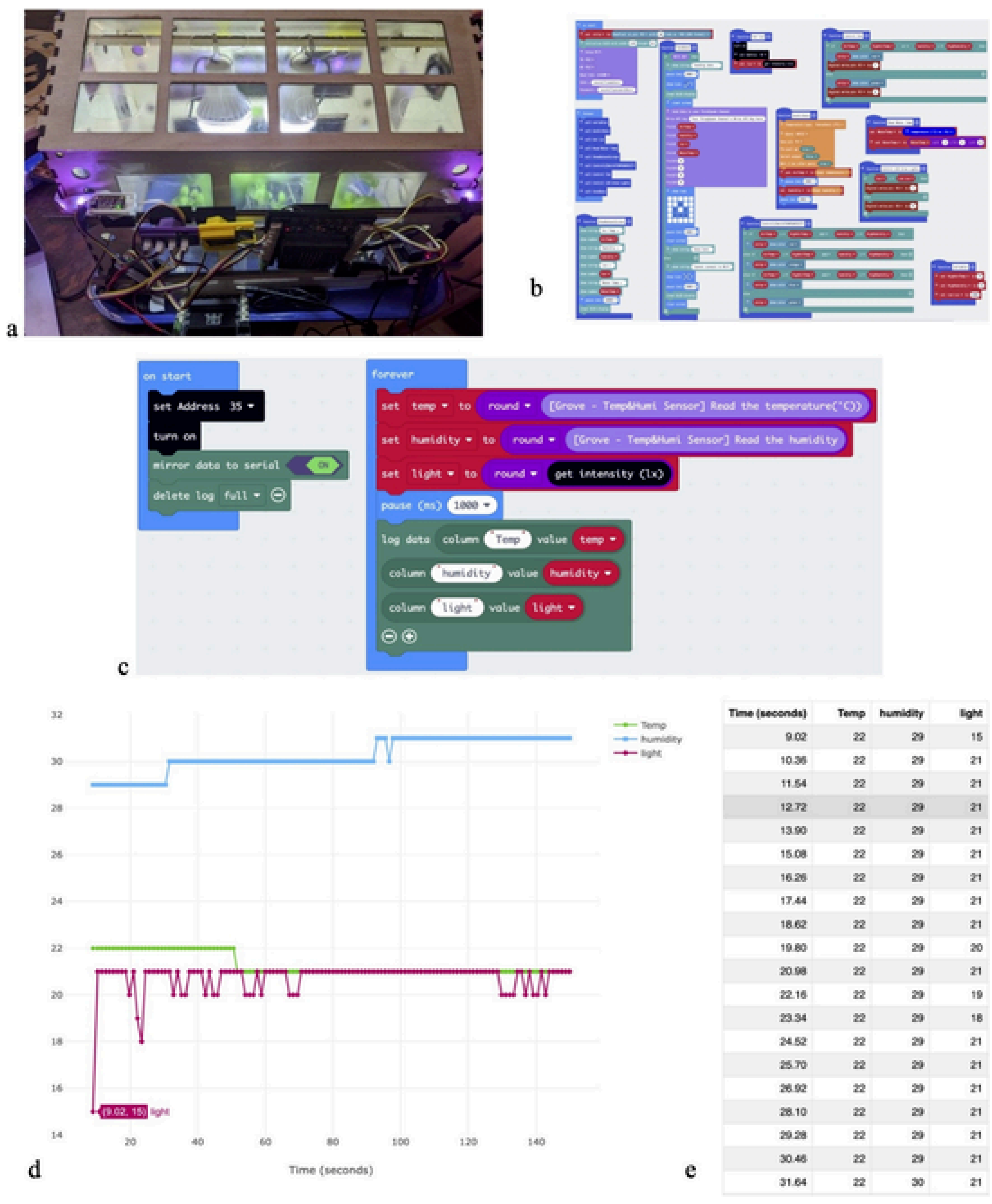
Summary of Curriculum Modules

#	Title	Description	Materials
1	Intro to BBC micro:bit and Microsoft MakeCode	Students tried programming using blocks in MakeCode (e.g., having the micro:bit show their names) and practiced how to connect the micro:bit with Chromebooks and how to download programs onto the micro:bit. Students also learned how to add extensions from the MakeCode library where they learned to program the LED strip to show different colors and color patterns	Micro:bit; Crowtail shield; LED strip
2	Temperature, Humidity and OLED Display	This module started with a review of related plant science concepts, including why temperature and humidity are critical to plant growth and what are good temperature and humidity levels for most plants. Then students learned how to define variables in MakeCode and how to set up a function to collect the temperature and humidity data using the sensor. To monitor the temperature and humidity in real time, they also learned how to set up the OLED display so that the display shows the real-time temperature and humidity data	Micro:bit; Crowtail shield; Temperature and humidity sensor; OLED display
3	Greenhouse Assembly with Engineering Design	Students were engaged in engineering practices such as assembling the parts, designing the details of the greenhouse (e.g., how many windows the greenhouse can have) and designing where and how to attach the various devices to the inside and outside of the greenhouse	Laser-cut greenhouse parts; 3D printed parts for holding devices
4	Data Literacy and Automated Data Logging	Students explored different types of data graphs (histograms, pie charts, etc.) and discussed what graphs can be used to answer questions. They also learned to program the micro:bit to automatically log the data collected by the sensors, export the data into google sheet and use the CODAP platform to plot the data	Micro:bit; Crowtail shield; Temperature and humidity sensor
5	Light Sensing and Automated Lighting	Students used a new sensor (light sensor) to automate a light bulb based on the light level data collected by the light sensor. Students learned the measurement of light levels (lux) and how to program a relay and the light sensor to control the light bulb	Micro:bit; Crowtail shield; relay; light sensor; light bulb
6	Air Flow and Automated Air Circulation	Students programmed fans via relays (specialized switches), to control the air flow inside the greenhouse	Micro:bit; Crowtail shield; relay; Temperature and humidity sensor; fan
7	Greenhouse Applications and Scientific Investigation	Students conducted an open-ended scientific investigation where they needed to decide what research questions they are interested in, design the greenhouse, conduct experiments and collect data to answer the research questions	Micro:bit; Crowtail shield; other devices based on the needs of student projects

Note. A more detailed description of the learning experiences of the modules can be found in our team's recent published paper (~~Authors~~Zhang et al, in press)

Fig. 1

Photos and screenshots for the final design. *Notes.* (**a**) physical structure of tabletop greenhouse; (**b**) complete code; (**c**) data-logging code; (**d**) data-logging graph; (**e**) data-logging table. Complete code should be readable at 200–300% zoom, and a larger image is available in Figure A1 of the Appendix. A source file is available upon request.



Time (seconds)	Temp	humidity	light
9.02	22	29	15
10.36	22	29	21
11.54	22	29	21
12.72	22	29	21
13.90	22	29	21
15.08	22	29	21
16.26	22	29	21
17.44	22	29	21
18.62	22	29	21
19.80	22	29	20
20.98	22	29	21
22.16	22	29	19
23.34	22	29	18
24.52	22	29	21
25.70	22	29	21
26.92	22	29	21
28.10	22	29	21
29.28	22	29	21
30.46	22	29	21
31.64	22	30	21

The final design of the smart greenhouse project employed 3D printing, laser cutting, micro-controllers and plug-and-play devices (e.g., sensors, actuators, displays). This design creates a low-cost and highly portable tabletop greenhouse that supports students in conducting scientific investigations around environmental and plant science (see Fig. 1A). Laser cutting was used to create the frames and exterior parts of the greenhouse (i.e., interchangeable side walls, windows and roof). 3D printing was used to create holders for the electronics that can be attached to the greenhouse.

The main electronic technologies used in the project are the widely available and low-cost BBC micro:bit coupled with a Grove Crowtail shield and plug-and-play sensors. The micro:bit is a pocket-sized computer designed for beginners to learn how to program and create interactive projects (Sentance et al., 2017). The Crowtail shield for micro:bit is a plug-and-play Grove extension board that features socket connectors. The shield acts as a bridge for solder-free connections with external devices. Prioritization of solder-free assembly minimizes burn risk and lead exposure while facilitating redesign processes. The core plug-and-play devices included (1) a temperature and humidity sensor; (2) a light sensor; (3) an OLED screen (128 × 64 dot matrix display) to show the real-time data of temperature, humidity and light levels inside the greenhouse; (4) an LED strip programmed to show different colors based on the environmental conditions; (5) a light bulb controlled using a relay that can be automatically turned on and off based on the light level, expandable to two bulbs if desired; and (6) two fans controlled by relays (specialized switches). For extension learning experiences, additional electronics were provided, such as speakers, LED lights, soil moisture sensors, mini humidifiers and heat mats.

All electronic components were controlled via programming of the micro:bit through Microsoft MakeCode. This Web-based programming platform features color-coded blocks and a switch to JavaScript, so that users can see the text-based code behind the blocks (see Fig. 1B and C). Each device is enabled through a MakeCode extension library. Students learn programming, in order to control and automate the greenhouse based on environmental data collected from the sensors. The data can be accessed and downloaded directly using a computer (through the data log functions available for micro:bit) or they can be streamed to a website (e.g., ThingSpeak™ Internet of Things [IoT] channels; see Fig. 1D and E). This enables teachers to guide students in analyzing, visualizing and interpreting data. Also, it allows students to experiment and see instantaneous results if they make any changes to the greenhouse.

Preparing Teachers for Classroom Implementation

One core aspect of the smart greenhouse work was to prepare teachers to become comfortable and confidence in leading the implementation in classrooms, as most teachers we worked with were science content experts yet possessed little or no coding knowledge. Through our iterative design of the teacher professional development (PD) program, we learned that experiencing the curriculum as learners, distributed teacher learning experiences and a more informal approach to PD were extremely valued and supported by teachers. Specifically, our teacher PD program included the following components: (1) weekly in-person trainings (one hour/week) for approximately 10 weeks, where teachers experienced the curricular modules as learners and discussed how to potentially implement the module in their classrooms; and (2) virtual community office hours of 90 min every week, which were optional for teachers to join to get one-on-one help with working on the electronic devices. Further, we recruited experienced:

teachers from the same school district who have implemented the smart greenhouse project before to serve as the PD instructors and facilitators, so that they could share experiences and help onboard new teachers. These experienced teachers would form a mentoring group to sustain and scale the project.

We also found that a longitudinal approach of teacher training was necessary and critical. It took teachers two to three years to become comfortable with the integration of coding into their science teaching, and over that period they slowly began to bring in their own approaches and adaptions to the instructional materials. Independent of grade band, all teachers initially focused on the teaching of coding and making sure that their students understood coding and how to correctly connect their sensors to view data. However, during their second iteration of teaching the project, they brought back the science and engineering design. In those iterations, the physical computing aspects of the project would drive the doing of the science. Teachers became much more comfortable teaching across disciplines, blending science, the use of data, engineering design and computation to support their student investigations.

Classroom Implementation Findings

The final design and the curriculum were tested in four, eighth-grade science teachers' classrooms, with a total of approximately 380 students. Classroom observations indicated that students were highly engaged (~~Authors~~Jackson et al.,; 2019, Asante et al., 2021a,; Jackson et al., 2022). Teachers noted that students who had not been engaged with science all year long "all of a sudden came alive" with the smart greenhouse project, and those students became motivated to learn science for the first time all year (~~Authors~~Cheng & Jackson, 2021b). Students were particularly intrigued by working with the LED strips in Module 1, and they experimented creatively in designing and controlling color patterns. They were excited to test how adding a mini-humidifier or a heater can change the conditions in the greenhouse and ultimately impact plant growth. Students were imaginative and brainstormed various scenarios where the automated greenhouse would be helpful, such as, "A student needs to visit her grandparents' house in the summer and will be away for two weeks." Overall, this greenhouse project turned out to become a capstone-oriented project for all eighth-grade students in the district, in which students were successfully exposed to key computational science concepts and how computation can be applied in modern scientific research (~~Authors~~Asante et al., 2021a). Teachers felt that students, particularly those from underrepresented groups, recognized their potential for computational science, data and natural science topics through this project.

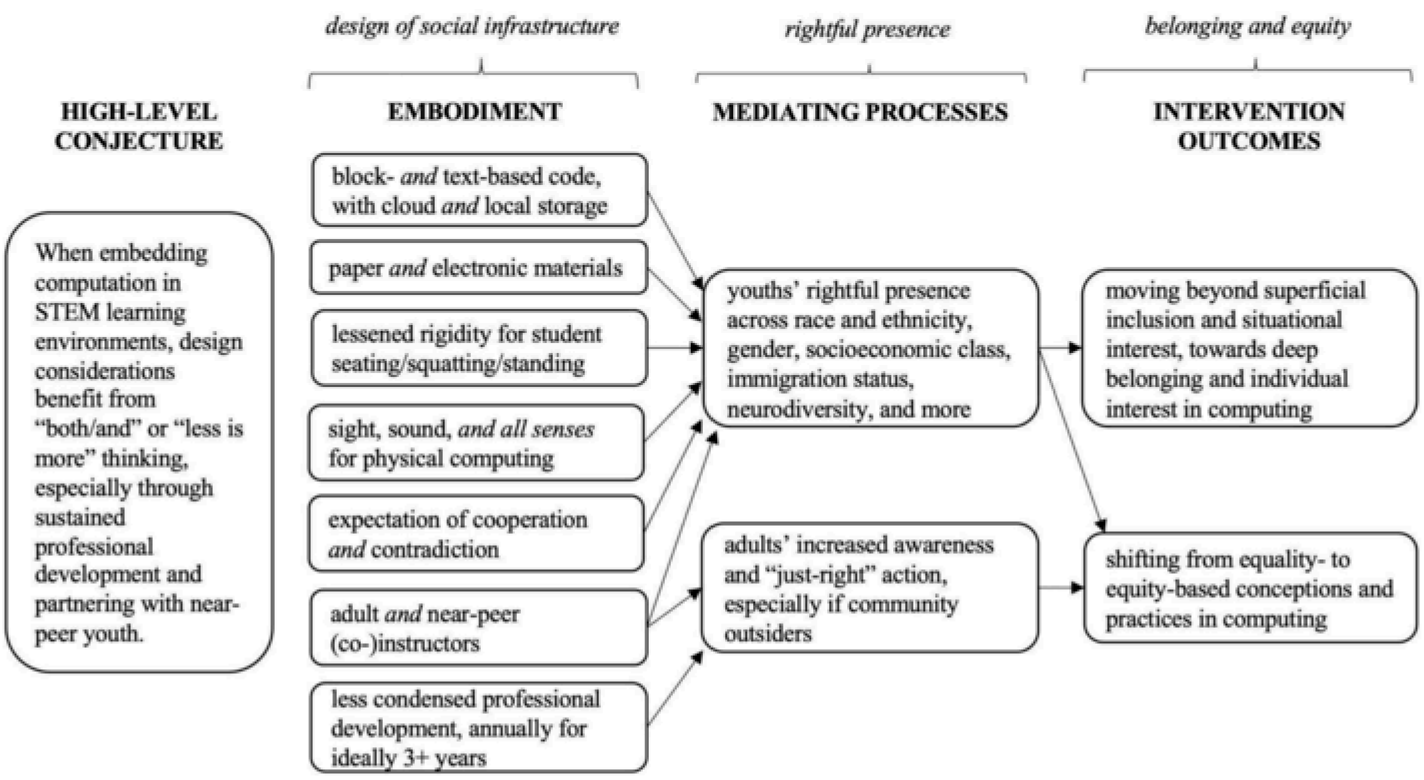
Our observations also captured that students worked best in pairs. Typically, one student was in charge of the programming (moving and organizing the blocks) and the other student focused on setting up the physical parts of the greenhouse (e.g., assembling the parts, securing the fans to the top of the greenhouse). They worked together to make decisions of the design, make sense of the codes and troubleshoot. The troubleshooting step in particular required collaboration of the two students in each pair, as it involved going back and forth between checking whether the code was correct (e.g., whether threshold values were set correctly) and whether the devices were correctly attached (e.g., wires were correctly connected). This involved multiple attempts at examinations, explanations and negotiations between the two students in each pair until they identified solutions. We found that almost all pairs needed to troubleshoot their greenhouse at multiple points during the project. Further, it often happened that multiple pairs had similar issues in the same class, and students would share if one pair figured out the solutions. This led to collaborations across pairs and to the advancement of collective knowledge of the whole class (~~Authors~~Asante et al., 2021a~~;~~; Jackson et al., 2022; Yang, 2023; Zha et al., 2020).

Critical Decisions

Though the team made countless minor decisions, by making a conjecture map (Sandoval, 2014; see Fig. 2) we arrived at seven of the most critical design decisions. We describe the most influential four due to space constraints. In general, these decisions manifested in various forms of *embodiment* in the learning environment, which, through specified *mediating processes*, supported the designed *intervention outcomes*. The three elements of embodiment, mediating processes and intervention outcomes are summarized in a *high-level conjecture* about educational design and learning.

Fig. 2

Conjecture map for how educational design facilitated student outcomes



The overall conjecture map shown in Fig. 2 is a synthesis of conjecture maps that we constructed after many of the iterations, especially whenever we made substantial changes. These maps often served a dual purpose, for the project itself and for various documentation requirements (e.g., annual reports for grants, presentations at conferences, assignments for coursework or components of dissertations). Examples of earlier conjecture maps, along with descriptions of the theories that informed them, are included in section A3 of the Appendix.

Shift from Text-Based Local Storage to Block-(and-Text-)Based Cloud Storage

From Spring 2018 to Fall 2019, we employed text-based coding in the microPython programming language and the EsPy Integrated Development Environment (IDE). The code was saved locally on university-owned laptops, then uploaded onto a WioLink 8266 microcontroller. Though the hardware and software provided robust functionality, these were incompatible with school-issued Chromebooks, and they lacked the automatic backups of a cloud-based solution. Accordingly, we periodically sought alternative cross-platform and browser-friendly options.

In Spring 2020, we piloted a block-based coding program (with a text-based option) in the Microsoft MakeCode IDE. In this case, the code was saved to the cloud via school-issued Chromebooks, then uploaded onto a BBC micro:bit microcontroller. MakeCode included a toggle between the default block-based format and a more advanced text-based format, which itself could convert between the Python and JavaScript programming languages. This setup had even greater functionality, required zero added computer resources (i.e., zero university-owned laptops) and facilitated automatic online backups (which students could access outside of school as needed or desired). Not only did this shift aid the transition to remote learning during the beginning of the COVID-19 pandemic, but it also proved more accessible with middle-school youth from that year forward.

The shift in modality supports coders with establishing expertise, as a block-based format reduces barriers presented by syntax (Weintrop & Wilensky, 2017; Zha et al., 2020). At the same time, the toggle to a text-based format supports coders with more intermediate or advanced expertise, or who are interested in the novelty or perceived rigor of that format. As for the shifts in hardware, they promote access for under-resourced schools, addressing equity related to socioeconomic backgrounds, which often intersects with racial and ethnic backgrounds (Blikstein, 2018). The compatibility with Chromebooks additionally enables emerging bilingual/multilingual youth to use built-in translation or dictionary tools, such as Read&Write by texthelp® for Google Chrome™.

Lessened Rigidity for Student Seating/Squatting/Standing

During our first iteration, out of concern for the expensive, university-owned laptops, we expected students to remain seated at table-desks (i.e., desk-height tables with no water or gas access). We did make some exceptions for neurodiversity (e.g., attention-related needs to be standing, rocking or pacing). Though this decision indeed protected the laptops and facilitated teacher circulation throughout classrooms, it also made table-desks crowded and cluttered.

For our second iteration, almost all students worked at lab tables, to facilitate physical access to the greenhouse hardware, as we doubled the number of microcontrollers to two. Though we were successful in that regard, some students who sat at lab stools appeared to be less engaged than their teammates (e.g., looking away from the greenhouse, hunched posture, talking rarely, etc.).

Our critical decision related to seating, in what Bielaczyc (2006) calls *student–teacher–machine–physical-space configurations*, occurred when we were forced to split students relatively equally between table-desks and lab tables, due to COVID-19 physical distancing requirements. This arrangement was so successful in promoting student engagement that we maintained it in subsequent iterations. Though this decision might seem obvious in retrospect to some reader-designers, at the time it was difficult to support the need for teachers to feel more secure when leading activities outside their usual expertise (i.e., coding, as opposed to the natural sciences), while promoting student agency (Asino & Pulay, 2019). Though some teachers grew in their coding expertise, some newcomers were encouraged to embrace flexible seating even amidst feeling less secure in their teaching. This encouragement ultimately promoted student engagement, even when we had zero assistant-teachers in Spring 2023, as part of our gradual release of responsibility. Namely, even though it felt disconcerting for some teachers to have students spread across twice the minimum feasible area (thereby limiting teachers' proximity for classroom management purposes), the combination of lab tables and traditional desks supported students who worked best when standing up, without overcrowding the lab tables. So, there was increased focus in students for whom sitting still can be challenging, without the distractions of all students being crammed into the classrooms' lab areas.

Inclusion of Adult and Near-Peer Co-instructors

We began the project with classroom teachers ("lead-teachers") and participant-researchers. Over time, we added "assistant-teachers", or high-schoolers who acted as co-teachers in classrooms or camps. The high-schoolers tended to be alumni of the smart-greenhouse project. That is, they usually had completed either a classroom- or camp-based unit or training as a middle-schooler. However, we did work with some high-school youth who had not previously completed a computer-supported plant-growing project.

In part, the critical decision to include high-schoolers as *near-peer* co-instructors (about two- to four-years' difference in age or experience; National Academies of Sciences, Engineering, and Medicine, 2019) was a natural consequence of longer-term capacity-building, especially in terms of developing expertise of adult- and youth-partners. At the same time, it was a deliberate decision, in recognition of the potential for near-peer teaching and mentoring to support academic, social and career outcomes (National Academies of Sciences, Engineering, and Medicine, 2019).

In addition to benefiting middle-school students and teachers, this decision promoted the high-schoolers' development of interest in teaching, STEM or both, and many of them went on to choose teaching and/or STEM majors in college. Also, the high-schoolers gained formal work experience, financial resources for themselves and/or their families and recommenders for future jobs or college applications.

In our final design, we phased out the near-peer co-instructors, in part due to financial limitations and in part due to releasing responsibility to the lead-teachers. However, in future iterations the lead-teachers may elect to include high-schoolers interested in credit-hours for high-school courses, volunteer-hours for student or community organizations or funding from non-university sources (e.g., state or federal programs for K-12 schools). For such funding, we have already held preliminary conversations with the district grant-writing coordinator and "dropout-prevention" specialist (alternatively, *school-persistence* specialist).

Shift from Summer-Concentrated to Spring-Dispersed Professional Development

After our first design iteration in 2018, we sought to redesign the smart-greenhouse project as a team of researchers and practitioners during summer, when the practitioners were most available. And though our redesign seemed to be an improvement on the first iteration, it was largely obsolete by the following spring. Also, there was some natural decay of practitioner learning. So, from iteration #3 onwards, we scheduled "spring-dispersed professional development", which manifested as roughly weekly meetings for about eight weeks before an intervention. We found that this format was a reasonable addition to the practitioners' workflows. It was close enough to the intervention to avoid technological obsolescence, and it was far enough from the intervention to allow for adjustments to the curriculum.

As noted elsewhere (~~Authors~~Asante et al., 2021a), the timing of professional development during the school year might be for after-school, during-school, weekends, vacation days or a mix thereof, depending on practitioners' and researchers' schedules. In general, the research team had more flexibility, and therefore deferred to the practitioners' availability. Ultimately, the practitioners were compensated for their time during extra training sessions, and the researchers sought to lessen any additional stressors as much as possible.

Concluding Thoughts for Critical Decisions

Through conjecturing mapping (Sandoval, 2014), we identified seven design decisions, of which we highlighted four in this section. These decisions focused on the embodiment of the learning environment, in efforts to shift mediating processes and intervention outcomes. Most of the decisions can be implemented with little or no added strain on resources of time, energy, finances and materials, whose scarcity already limits equity of access to learning experiences in computing (Blikstein, 2018). Even though these decisions supported improvements in teacher confidence and student engagement, our final design still has some important limitations, which we discuss in the following section.

Design Limitations

Design feedback gained through student responses, interviews and observations shared across daily participant-researcher team after-action meetings identified multiple readily actionable opportunities for improvement and future iteration. In particular, these opportunities regarded student rightful presence, project ownership, instructional material delivery, material logistics and group learning dynamics. Of major interest to the research team were factors that influenced student interest, engagement and adhesion to proscribed project progression, as well as expressed interest in continued use of assembled greenhouses.

Linguistic Affordances and Limitations

Given the eighth-grade student population at Mills City is both culturally and linguistically diverse, with a large recent immigrant population to Mills City, instructional materials were provided in the two primary languages spoken in student homes, as well as in two different language versions of slides. Provision of materials in multiple languages has been a deliberate design response to prior project iterations. Not all students in the eighth-grade population are guaranteed to be fluent English speakers, and for students with developing ability in what for some may be English as a third or fourth language, the opportunity to concept- or understanding-check instructions in their home language can facilitate engagement.

Provision of multiple-language instructional materials increases the ability of all members in multilingual student program cohorts to engage with coding concepts and explanations or examples. without needing supplementary translation by a peer. We consider peer consultation as a social obstacle for students to be reliant on others for interpretation of instructions and materials. Rooting STEM + C experiences in reliance on monolingual mastery may inadvertently associate STEM learning experiences with judgment of their English language skills, for example, despite coding itself representing a more consistent linguistic experience. The benefits of materials accessible in languages students are most confident in conveys the best possible chance that students may see the target material as accessible and approachable, reading for understanding rather than being gated by translation nuance. In particular, when considering that we are introducing students to tools of self-reliance, we must also ensure we do not undercut student confidence and sense of self-efficacy by requiring that students from marginalized or minority linguistic groups rely on peer interlocutors for understanding or decision-making.

One frequent observation shared during after-action meetings regarded the use of only one language version per student team, chosen by each pair. For bilingual students working alongside peers who preferred alternate-language instructional materials, this commitment may have been less meaningful, but it would otherwise potentially gate the linguistic diversity feasible within one project team. Future iterations may opt to address this by providing dual-language material, which could also facilitate increased multilingual familiarity with key terms.

Past Attempts and Further Opportunities to Foster Rightful Presence

We conceptualize rightful presence per Calabrese Barton and Tan (2019) as legitimate presence and participation for an individual in a group and setting of which the individual is inherent and integral. In other terms, the class must be incomplete without the involvement and contributions of all students. Cognizant of the design pressure to support a multilingual student population with monolingual or limited bilingual instruction, the design team considers agricultural and other food-linked practices as valuable applications. These practices may ground engineering projects in subjects that are central and readily accessible across cultures.

The selection of one primary plant crop (basil) for all greenhouses missed an opportunity for students to connect garden practices with their individual home cultures, a decision accounting for the ubiquity of our selected herbaceous plant in seasonings cross-culturally. While standardizing the seeds chosen allowed for higher confidence in all teams obtaining viable sprouts for installation and sample redundancy, this was at the expense of encouraging students to grow plants which they or their caretakers might regularly purchase and cook (e.g., cilantro/coriander, kale, mint, various peppers, etc.). Personalization of what is grown in each smart greenhouse is especially relevant for diverse populations, as this may entail interest in growing plants from different subclimates and regions. That interest in turn creates a personally meaningful extension opportunity for changing the humidity and temperature thresholds we suggest for our model plant, placing students in the role of investigator and expert for the care of their plants. This role may require sequence changes to allow for seed selection and effective germination before project completion.

Plant selection and cultivation represents a subtle opportunity for designers to create space where students view participation as contribution and co-learning about topics for which they may have limited prior exposure or interest. For example, students who harbor a love of chilis and see programming as a means to grow chilis at home might perceive science and engineering as a useful path to culinary satisfaction. Direct connection of STEM applications and concepts to topics that middle school students are frequently confident discussing is a deliberate strategy. This approach represents physical engineering and coding as meeting self-identified needs and as paths towards self-sufficiency and self-expression, especially for students who may not be interested in computing but value the ability to contribute to or support others with a computing and engineering skill-set.

Similar heterogeneity existed among student exposure to and interest in coding or engineering practices. Students reported taking computer science classes, though for some students these classes had occurred in elementary school while others were enrolled in after-school STEM clubs. This design's tailoring of engineering task difficulty and accessibility alongside sufficient complexity, to engage those with more well-developed or emerging interests in coding and engineering, involved the swift introduction and integration of multiple sensor types and complex sequencing. Within the bounds of limited class-time, our team produced an accessible progression utilizing each sensor, including optimistically-judged assembly time. Occasionally, physical assembly challenges left students with little buffer time to experiment, or to make multiple productive mistakes and remain on-pace with the class, without occasionally relying on the provided example code.

Need of Further Mitigations for Time- and Material-Based Constraints

The "time crunch" aspect of the project manifested in several forms. For example, students who had difficulty accessing or reloading code, who contended with equipment issues or who may have been less familiar with block-based programming were often running behind, with ripple effects to scheduling. Due to similar concerns, student groups were often unable to explore many of the extension activities included within each module. The impact of project pacing on group engagement dynamics was also apparent in peer-support practices, with a focus and emphasis on reaching the end of each module. This focus was often observed in the form of students radiating from "finished" groups to help or re-engage with groups which were "behind" or "stuck" near the end of the class period.

The design team in this instance considers the complexity of the smart greenhouse inclusive of fabricated parts and available sensors to be at odds with the appointed time frame. Student-participants are engaging with novel material at a pace that may preclude effective understanding or transmissibility of concept. Ensuring that students have sufficient time to experiment with and familiarize with the concepts introduced in each module may be more important to stimulating and sustaining interest, relative to leading students through a more complex project that they may not have time to digest. It is possible that the pace and schedule of the smart greenhouse project were also sources of stress for students debugging code, hunting for sequence or wiring errors and similarly stuck in a fixed progression.

The inclusion of complete example code in the instructional materials was aimed to support students in checking their own code for errors during the learning process. However, for many students the provided examples also became an alternative source of code to replicate at the end of class in order to be ready for the following module. Fortunately, with small groups and the ability for cross-group interaction, researcher-participants also consistently witnessed students openly seeking out opportunities to help their peers complete each module, limiting the proportion of students who opted to “copy the answer”.

Through applying engineering principles and tools to facilitate crop growth, the smart greenhouse project embraces the principle of horizontality in education, that is, considering and evaluating concepts and skills learned in one setting as applicable within other lived contexts including those that are informal and extracurricular (Warren et al., 2020). In this case, the horizontality related to the use of coding skills applied to farming. Our greenhouse project embraces learning as a means of gaining skills that support students’ families through growing much-loved and culturally relevant herbs, establishing a norm of applying coding concepts in informal spaces as an additional means of contribution and experimentation. Our current design prioritizes understanding and application of physical computing concepts to maintain enclosure conditions via utilization of sensors, scheduled cycling and expression of lighting equipment and sensor-gated automation of airflow via fan power supply manipulation. Redesign and reapplication of these greenhouses to target plants requiring humidity in far excess of local conditions – for those at high altitudes and low latitudes – may benefit from inclusion of insulation concepts alongside suitable supply for skill development. This extension would also enable an alternative path of fungi cultivation, expanding the range of culinary and academic applications in step for classrooms with an interest in decomposition cycle labs, while generating compost for further horticultural hijinks.

Student-participants in shorter-term programs may have limited opportunities to develop and cultivate other applications for their burgeoning skills if the pace demands quick execution over experimentation. One example of this particular design challenge in the smart greenhouse program was the integration of temperature and humidity maintenance, settings that are critical to plant health but also must be tailored to specific crop germination needs. Establishing deliberate designs wherein students select seeds from community or culturally-relevant foods, or those of personal preference, requires enough program time for all seeds to germinate within the program time period. There also must be support in understanding differences in the native and ideal habitats of choice herbs (e.g., chives versus mint).

Initiatives and other programs working respectfully within academic scheduling constraints may need to standardize the plants grown for the sake of ensuring that students experience germination success, as with our selection of basil as our design target plant. We recognize that a consequence of this choice is standardization of humidity and temperature settings across greenhouses and student team learning, which may aid with plant and greenhouse outcome comparison. However, there is also a cost of not providing students an additional opportunity for personal investment and interest capture, through the opportunity of choice and experimentation with fan settings. We contend that, beyond considering the mean time-to-completion for program challenges, ensuring sufficient program buffer time for concretization of concepts will create space for multiple representations and opportunities for productive failure (Kapur, 2008; Song, 2018), wherein students incorporate knowledge from seemingly silly experiences and experiments into their projects.

Logistically, multiple considerations arose during the smart greenhouse project administration that are of particular relevance to in-school delivery of STEM + C programming. While 100% of the smart greenhouse supplies were provided through research funding rather than either participating Mills City school, the number of greenhouses that required in-classroom storage and electrical access necessitated clearing of substantial classroom space during the final quintile of the school year, while also featuring notable variation in natural lighting. Placement for greenhouses, alongside consistent power access, may require dedicated mobile or vertical storage solutions beyond available counter space during the school year. Additionally, while surplus parts laser-cut or 3D-printed by the design team were available, the attrition rate of equipment was impactful and highlighted the need to expand our project’s anticipated spare supply needs. More spare parts are necessary to ensure no teams are rendered unable to complete their enclosure or need to cannibalize other kits for parts, given the difficulty of same-day replacements.

Potential for Increased Physical and Symbolic Ownership of Greenhouses

Greenhouse physical ownership and personalization in this iteration of the project was resolved on a case-by-case basis, and students expressing interest in their team greenhouse were allowed to individually claim one for home use. There were complications with this, as the ratio of greenhouses to students post-attrition was less than 1:1. So, the team opted to offer greenhouses to students who expressed independent interest in keeping one, rather than planning for all students to have a personal smart greenhouse.

While the overall bulk of greenhouses remained on school facilities for future use, the ability of students to obtain and learn to use a microcontroller alongside an experimental garden may represent an expansion of opportunities to conceive of and engage in programming challenges of their own volition, and to design for students who might otherwise not have home access to similar engineering tools. Finally, individual greenhouses with personalized decorations or designs may support student project investment and symbolic ownership, via creating customized and easily identifiable accoutrements, which may be considered student-driven activities that may increase at-home experimentation.

Final destinations and disposition of the smart greenhouse supply represent a prospective indicator both of student interest levels at program cessation, with the physical greenhouses representing long-term access to ongoing coding and experimentation for student-participants. Researchers regarded this conversion rate to greenhouse-keepers as an informal straw-polling of student interest transition, namely from the consistent engagement typical of student sustained interest witnessed during programming, into emerging and well-established interests where students pursue and create opportunities to apply coding and other design technical skills outside of scholastic settings (~~Authors~~Jackson & Abdus-Sabur, 2024; Hidi & Renninger, 2006).

The sizing, portability, material production methods, focus on culinary contribution and aim of establishing individual student connection to the process and expected products of gardening labs was predicated on the ongoing access to and use of greenhouses by students at school and home. The greenhouses are theirs, and thus they have an ongoing right to experiment and use these tools for self-expression and independent skill cultivation, in a format that presents students to their home community as learning a skill oriented toward contribution. In ~~Authors~~Jackson & Abdus-Sabur (2024) we expand on the implications to student interest development of local community feedback vis-~~a~~à-vis student rightful presence or participation surrounding student behavior (*Do adults approve? Is this permitted?*); the role of alignment with student personal goals in guiding future student engagement (*What does this have to do with me?*); and the criticality of regular access and means of both expression and extension of skills on self-schedule for students to voluntarily deepen their interest in STEM.

Reflections

We reported our instructional design case (Howard, 2011; Moore et al., 2023) as developed across 14 iterations of computer-supported plant-growing projects. As mentioned in the Introduction, we hope that sharing our experiences is generative for readers of this manuscript. In response to the first research question about how to design learning experiences, we found that the use of conjecture mapping (Sandoval, 2014) and the Social Infrastructure Framework (Bielaczyc, 2006) provided educational design considerations to support youth engagement in STEM + C, especially when combined with social interdependence theory (Johnson & Johnson, 2009) and self-efficacy theory (Bandura, 1977; DiBenedetto & Schunk, 2018). We are optimistic that these considerations could prove transferable to learning environments throughout science classes in grades six through 12 and for non-science majors in grades 13 through 16.

With regard to the second question about resources we need to provide for adult and youth (co-)instructors, we found that materials needed to be as low-cost as possible, coding environments needed to be Chromebook-compatible and cloud-based, professional development worked best when chunked into weekly one-hour sessions and about two or three years was needed to gradually release responsibility to any given teacher (ideally with near-peer support for the students). These findings might not be the most novel, but they could help reader-designers remember things that we might take for granted. Finally, though our design is not free of failures (as noted in the Design Limitations section), it has proven adaptable across in- and out-of-school-time spaces, resonating throughout young and middle adolescence, in ways that can support – albeit not guarantee – students' rightful presence (~~Authors~~Jackson & Abdus-Sabur, 2024; Calabrese Barton & Tan, 2019; Squire & Darling, 2013).

For reader-designers interested in adopting and scaling-up a similar intervention in-school-time, we recommend coordinating with district or network leadership, to find the best time(s) of the school year to run such a project (e.g., right before or after school vacations; immediately following year-end high-stakes testing; during winter, spring, or summer breaks; etc.). Further, we encourage reader-designers to coordinate with leaders who can facilitate sharing of materials across grades and departments or subjects, to support the cost effectiveness of interventions.

Usefulness of Social Infrastructure Framework and Conjecture Mapping

Throughout the 14 iterations of this educational design, including the major shifts in modality and locality of code plus moderate revisions to the hardware, we found that Bielaczyc's (2006) Social Infrastructure Framework (SIF) and Sandoval's (2014) conjecture mapping remained as useful tools for analyzing and refining design. The SIF supported us in reconciling the intended and enacted educational designs, through its four Dimensions of *Cultural Beliefs*, *Practices*, *Socio-Technical-Spatial Relations*, and *Interaction with the "Outside World"*. Of the 14 total Design Considerations across those four Dimensions, the ones we found most useful were *The associated participant structures of students*, *The associated participant structures of teachers*, and *How a student's social identity is understood*. Those considerations proved especially helpful when integrating high-school youth and co-instructors for middle-school interventions, and in gradually releasing responsibility from university personnel to K-12 faculty and staff. For further details, see section A3 of the Appendix, including two examples in Figures A2 and A3.

Even when constructs secondary to student engagement shifted over time (interest, identity, relationship with science, affective domains, etc.), our two major design frameworks proved to be flexible and adaptable. Though we three co-authors approach this work primarily as educational designers, we imagine that the SIF in particular could prove useful for classroom teachers, and that administrators might find utility in conjecture mapping (e.g., when creating school or district improvement plans).

Perspectives of Stakeholder Groups

As we look back on more than five years of work, we recognize some commonalities and differences across a variety of stakeholder groups. When considering youth themselves, adults who work directly with youth (i.e., teachers and parents/guardians) and those slightly more removed (researchers, administrators, community members, etc.), virtually all stakeholders had some interest sparked by the novelty, aesthetics and relevance of the computer-supported plant-growing projects. Most had never seen in real life a tabletop greenhouse or a multitiered hydroponics system. The inclusion of LED light strips for signaling and ornamental purposes was a particularly attention-grabbing feature across classrooms, camps, community showcases and public outreach events. And though at times we used monocultures of basil or microgreens for logistical reasons, in many cases the extra effort to expand plant options was worthwhile for those who preferred options such as cilantro, lettuce, strawberries and various sweet or spicy peppers.

Regarding the various schedules of our intervention, in each case the timing seemed ideal for most if not all stakeholders. The in-school-time interventions with Mills City Public Schools happened between the culmination of state-mandated testing and the end of the school year. This time of year previously had been reserved for *another* round of testing, created by the district. However, administrators, teachers and students alike welcomed the project- and team-based nature of the smart-greenhouse interventions. For out-of-school-time implementations in Mills City, the camps were popular with families who otherwise had limited access to childcare or vacation programs. That is, without the vacation camps, many youth would have stayed at home all day. As for the Rifton intervention, we worked around the cooperating teacher's schedule, visiting her classroom roughly once a week to add some variety to her standard curriculum. Finally, with respect to Hillside University, the project proved flexible during times of quarantine and remote learning. Namely, undergraduates could –

and did – work asynchronously at all hours across the globe, through a combination of scaffolded curricular materials and flexible office hours or email-based communications.

Narrowing our focus now upon the educational design and research team, we found the overall design to be suitably flexible across disciplines of science and research constructs of interest. Namely, the pluridisciplinary nature (Hofstetter, 2012) of the design enabled teachers and youth to draw upon existing interests without overpowering other interests (~~Authors~~Jackson & Cheng, 2022). And though development of interest (Hidi & Renninger, 2006) was one well-suited research construct, the project also aligned with related constructs like engagement, motivation, and identity (Chen et al., 2019; Gee, 2000; Järvelä & Renninger, 2014; Reynolds & Caperton, 2011). In brief, as various graduate students phased in and out of the research team, their own foci resulted in quantitative and qualitative data suggesting that the individual constructs were positively developed with youth (~~Authors~~Jackson et al., 2019~~,~~; Asante et al., 2021a~~,~~; Jackson et al., 2022). So, there were ample opportunities for research assistants to leverage their own interests and expertise, while still supporting the overall goal of (re-)engaging youth in STEM + C disciplines. At the level of theory, we often thought with self-efficacy theory and social interdependence theory (Bandura, 1977; DiBenedetto & Schunk, 2018; Johnson & Johnson, 2009).

Concluding Thoughts

The overall arc of our work in physical computing (Hsu et al., 2017; Sentance et al., 2017) served as a bridge from more person-generated data analysis during our past work in urban ecology (~~Authors~~Barnett et al., 2006) toward more computer-generated orientations moving forward (e.g., via artificial intelligence [AI]). As the next phase of work is still very much under development, we leave in our wake a project with hardware, software, curriculum materials and social infrastructure that can support student learning in STEM + C, while still leaving space for data science and AI applications. We hope that this well-developed educational design proves useful to educational designers in the shorter-term, as further designs are developed in the medium- and longer-term. **AQ4**

Publisher's Note

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Data Availability

The datasets for this study are confidential per protocol #1000 with the Institutional Review Board of Boston College, with informed consent from all adult participants/guardians and informed assent from all youth participants.

Declarations

Competing Interests

The authors have no conflicts of interest to declare.

Supplementary Information

Below is the link to the electronic supplementary material **AQ5** .

Supplementary file1 (DOCX 1226 KB)

References **AQ6** **AQ7**

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