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Received: 22 September 2023 | Revised: 1 October 2024 | Accepted: 7 October 2024

DOI: 10.1002/tea.21998

RESEARCH ARTICLE

JRST | WILEY

Secondary science teachers' conceptualizations and modifications to support equitable participation in a co-designed computational thinking lesson

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Funding information
National Science Foundation, Grant/Award Numbers: CNS-1138461, CNS-1441041, DRL-1020101, DRL-1640201, DRL-1842374; Spencer Foundation, Grant/Award Number: 201600069

Abstract

Increasing access to computational ideas and practices is one important reason to integrate computational thinking (CT) in science classrooms. While integrating CT into science classrooms broadens exposure to computing, it may not be enough to ensure equitable participation in the science classroom. Equitable participation is crucial because providing students with an environment in which they are able to fully engage and participate in science and computing practices empowers students to learn and continue pursuing CT and science. To foreground equitable participation in CT-integrated curricula, we undertook a research project in which researchers and teachers examined teacher conceptualizations of equitable participation and how teachers design for equitable participation by modifying a lesson that introduces computational modeling in science. The following research questions guided the study: (1) What are

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teachers' conceptualizations of equitable participation? (2) How do teachers design for equitable participation through co-design of a CT-integrated unit? Our findings suggest that teachers conceptualized and designed for equitable participation in the context of a CT-integrated curriculum across three primary dimensions: accessibility, inclusion, and relevancy. Our contributions to the field of science teaching and learning are twofold: (1) obtaining an initial understanding of how teachers think about and design for equitable participation is crucial in order to support teachers in their pursuit of creating equitable learning experiences for CT and science learners, and (2) our findings show that we can study teacher conceptualizations and their design choices by examining specific modifications to a CT-integrated science curriculum. Implications are discussed.

KEYWORDS

computational thinking, equity, in-service teachers, secondary science

1 | INTRODUCTION

Broadening participation in computing fields is one important reason to integrate computational thinking (CT) in disciplinary classrooms (Grover & Pea, 2013; Wilensky et al., 2014). While there have been several discussions of what CT encompasses, there is a growing consensus that positions CT as a method of learning and understanding that utilizes key concepts from computing to solve problems, communicate information, and exercise critical thinking (Grover & Pea, 2018; Papert, 1993; Selby & Woollard, 2013; Wing, 2006, 2008). Our team has worked for several years to integrate CT in science lessons, but we have found that not all students engage in and relate to CT in similar ways, raising concerns about whether or not our curricula supports equitable participation (Zhao et al., 2022). While integrating CT into science classrooms may broaden exposure to computing, it may not be enough to ensure equitable participation in science and computing education. We argue that the design of CT-integrated science learning environments should include practices that are inclusive and engaging for all learners, supporting equitable participation in CT-integrated science lessons. However, more research is needed about how to support equitable participation in contexts that integrate CT and science.

Similarly, integrating teaching practices and curricular materials that support equitable participation in science classrooms can be challenging (Barton, 2000; Bianchini et al., 2003). As agents of change in educational systems, teachers exercise significant influence over the design and implementation of new practices in science classrooms. To foreground equitable participation in CT-integrated curricula, we undertook a research project in which researchers examined

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how teachers understand and design for equitable participation by modifying a science lesson that introduces CT practices. The following research questions guided the study:

1. What are teachers' conceptualizations of equitable participation?
2. How do teachers design for equitable participation through co-design of a CT-integrated unit?

2 | LITERATURE REVIEW

As computation and science have become inextricably linked, many argue that CT should be integrated in science classrooms (Grover & Pea, 2013; Grover & Pea, 2018; Lee et al., 2020; Sengupta et al., 2013; Weintrop et al., 2016). In fact, the Next Generation Science Standards, standards that have either been adopted or adapted as science learning standards in the majority of the United States, lists Computational and Mathematical Thinking as one of eight science and engineering practices (National Research Council, 2012; NGSS Lead States, 2013).

Papert began a discussion of CT by describing computing as an essential component of everyday life that would become a new way of thinking and making sense of the world (Papert, 1980). Wing coined the term CT and defined it as “the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent” (Wing, 2011, p.1). Others then expanded on this definition to include specific CT thought processes that included the ability to think in terms of abstractions, decomposition, algorithms, evaluations, and generalizations (Selby & Woollard, 2013). Many others have defined and operationalized CT in various ways in many contexts (e.g., Brennan & Resnick, 2012; Grover & Pea, 2013; Kalelioglu et al., 2016; Shute et al., 2017). While there is growing consensus on the definition of CT, how it should be integrated with other topics is still undefined. Yet, its integration into science is growing (reviewed in Wang et al., 2022). The taxonomy of CT practices for science and mathematics outlines a framework that specifically outlines the CT practices that are used in service of mathematics and science (Weintrop et al., 2016). These practices include computational modeling, data, problem solving, and systems thinking. This is the framework we use to integrate CT and science at the high school level. This article will primarily focus on computational modeling CT in science practices. We focus on computational modeling because our teacher partners integrate computational modeling more than any other CT practice for science, and we leverage this interest to build further engagement with CT and science in curricula.

2.1 | CT and science integration

Research indicates that integrating CT into science supports student learning (Barr & Stephenson, 2011; Gunckel et al., 2022; Guzdial, 1994; Jiang et al., 2024; Krakowski et al., 2024; Levy & Wilensky, 2009; Peel et al., 2019). Including CT in science classrooms promotes accessibility in CT practices, such as computational modeling, by increasing the number of students impacted. Previously, principles of CT were primarily taught in computer science classes and/or after school programs, both of which are learning experiences that typically must be opted into. In contrast, science courses, such as biology, tend to be required courses (Margolis, 2017; Mouza et al., 2020). Our work focuses on high school science to support efforts in broadening participation in computing ideas and practices by incorporating CT in the science classroom. By teaching CT practices in compulsory science classrooms, CT integration allows more students to have access to a set of computing practices, skills, and ideas that have typically been available only to students who opt into computer science classes (Barr & Stephenson, 2011; Grover & Pea, 2013; Weintrop et al., 2016).

2.2 | CT and equity

There are many words, phrases, definitions and approaches to equity in education. "Equity typically refers to having access to what is needed" (Lewis et al., 2019, p. 482), rather than equal access to everyone. Diversity "refers to which groups are and are not represented or included in various spaces and practices" (Lewis et al., 2019, p. 482). Access focuses on the access to materials and content needed to engage in the educational topic (Lewis et al., 2019). According to American Psychological Association (2021), equity, diversity, and inclusion are achieved by "eliminating structural barriers and scientific practices that have prevented the full participation of [marginalized] groups." In this work, we refer to equitable participation as providing students with an environment in which they are able to fully engage and participate in science and CT practices. We argue that fully engaging in integrated CT and science makes learning more equitable and may help students feel empowered to continue learning computer science in the future. This may, in turn, impact diversity in computing-related careers. In the following sections, we will review approaches, frameworks, and research related to equity in education broadly, science education, computer science education, and teacher education.

2.2.1 | Equity in education

Culturally relevant pedagogy and teaching is a framework often leveraged for equitable participation in education. Culturally relevant pedagogy has three criteria: "Students must experience academic success, students must develop, and/or maintain cultural competence, and students must develop a critical consciousness through which they challenge the status quo of the current social order" (Ladson-Billings, 1995a, p. 160). This approach focuses on giving all students what they need to be successful and has been incorporated into multicultural education to support collective empowerment of students. Critical race theory (CRT) has also been incorporated into multicultural education to push beyond traditional approaches and include critical dialog to challenge the universality and objectivity of knowledge (Ladson-Billings, 2004). "CRT is about deploying race and racial theory as a challenge to traditional notions of diversity and social hierarchy" (Ladson-Billings, 2004, p. 57). It operates under the following assumptions: racism is present and normal in our society, racial, and other oppression can be challenged through storytelling, and society only advances ideas/agendas from minoritized groups when it is beneficial to the people in power (Ladson-Billings, 2004). School curriculum usually is designed by the dominant culture and "maintains the current social order" (Ladson-Billings, 2004, p. 59). Instruction and pedagogy typically contribute to systematic exclusion by not connecting to students' lives or identities and failing to discuss and question social systems and power (Ladson-Billings, 2004). Assessments contribute to inequity by favoring the dominant culture and excluding nondominant cultures, leading to an assessment system that makes nondominant students feel inadequate (Ladson-Billings, 2004). Approaches such as culturally

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relevant pedagogy and CRT promote equitable education, but how to integrate these approaches widely and prepare teachers remains challenging (Barton, 2000; Goode et al., 2020; Ladson-Billings, 1999, 2004).

2.2.2 | Equity in science education

A recent review of literature on race and ethnicity in science education indicated that there needs to be more theorization about the roles of race and ethnicity in science education (Mensah & Bianchini, 2023). The authors suggest that science education researchers should "acknowledge that issues related to race and ethnicity, as well as language and other social markers, are highly contentious in our society" (Mensah & Bianchini, 2023, p. 251). Scholars have leveraged culturally relevant pedagogy and CRT in science education to shed light on successful strategies for supporting diverse students. For example, science educators should focus on changing power structures in the classroom, employing relevant science contexts, using science as a tool for change, and learning in communities (Barton, 2003). Learning in informal and community programs has allowed students to meaningfully blend the social and science worlds, allowing them to engage in their community in ways that mattered to them and identify as people who are knowledgeable (Barton & Tan, 2010). Connecting to students' interests and real-world problems supports culturally responsive computing and can lead to positive STEM perceptions and experiences (Fischback et al., 2020). Given the successes in informal settings, science educators need to reevaluate school science and nonschool science and broaden what is considered science to include and value nonformal science and other forms of knowing (Barton & Yang, 2000). This redefinition of science will make science education more inclusive (Barton & Yang, 2000).

2.2.3 | Equity in computer science education

Culturally responsive computing brings culture and critical theory to computer science education and includes the following tenets:

- All learners are capable of digital innovation
- The learning context supports transformational use of technology
- Learning about one's self in various intersecting sociocultural lines allows for technology innovation
- Technology should be a vehicle in which students reflect and demonstrate understanding of their intersectional identities
- Barometers for technological success should consider who creates, for whom, and to what ends, rather than who endures socially and culturally irrelevant curriculum (Scott et al., 2015, pp. 420-421)

Utilizing culturally responsive computing, E-textiles, crafting, and making with open-ended projects have supported student learning and engagement with science and computing and increased perceptions of STEM (Searle et al., 2019; Searle et al., 2023; Tofel-Grehl et al., 2016; Tofel-Grehl et al., 2017; Tofel-Grehl et al., 2022; Tofel-Grehl & Searle, 2017). These works show how hands-on and inquiry driven activities provide avenues for nondominant students and girls

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to identify with school science. Providing multiple access points to science, such as crafting and making, may help students who do not relate to traditional science education make more meaningful connections to course content. Others have proposed a social justice approach to computer science education where the focus is on the "role of ethics in the curriculum, the role of identity in CS learning environments, and the significance of a clear political vision for CS Education" (Vakil, 2018, p. 26) that is "anchored in peace, antiracism, and justice" (Vakil, 2018, p. 36). This social justice approach calls for deeper engagement with equity beyond inclusion and representation, which are needed in CS education (Vakil, 2018). While these frameworks and approaches are promising, they are still not widespread.

2.2.4 | Equity in teacher education

The literature suggests that teacher education has not effectively prepared teachers to teach diverse students (Ladson-Billings, 1995b, 1999, 2006). While efforts to support multicultural education for teachers exist, they are not the norm in teacher education programs (Ladson-Billings, 2006). In science education, Barton (1999, 2000) has developed a teacher education program for preservice science teachers that engage them in service-learning where they engage with children through community centers, such as homeless shelters (Barton, 1999, 2000). This work showed that service-learning is useful for supporting multicultural science teaching practice because preservice teachers were able to broaden their multicultural science education conceptions and begin to question their knowledge base and actions more often. Preservice teachers questioned their role as a teacher, what the classroom is for, the role of science education in society, and they began analyzing forms of knowledge and paying attention to power dynamics in classrooms. Barton attributes these shifts to preservice teachers' ability to engage with children in nonschool and unfamiliar settings, which allowed them to reflect on their beliefs and form relationships with communities and children as children, rather than students (1999, 2000). Ladson-Billings also calls for teacher and student interactions outside of the classroom because they need to learn to observe culture first, especially in communities where they will teach (Ladson-Billings, 2006). Ladson-Billings argues that teacher education should involve more global connections so students can understand more of the world and differences in education globally. She believes CRT can help prepare teachers to teach diverse students (Ladson-Billings, 1999). Increased understanding of culture should help preservice teachers "not contribute either to the culture of poverty or the poverty of culture" (Ladson-Billings, 2006, p. 109).

Translating these approaches into widespread teacher education is challenging (Barton, 2000). Culturally relevant computing pedagogical strategies are important for broadening participation, but, in order to implement them, an understanding of school structures and how they impact students' pathways in computer science education and careers is needed (Goode & Ryoo, 2019). Goode and colleagues investigated whole-school support strategies to implement equitable computer science (Goode et al., 2020). They found that, in order to actually broaden participation and engagement of historically marginalized students, "schools must attend to the technical, pedagogical, political, and normative dimensions of 'Computer Science for All' efforts" (Goode et al., 2020, p. 11). They also found that teachers who are committed to participating in social change in their classrooms, schools, and communities are essential agents that facilitate change. They argue that equity needs to remain at the core of reforms; otherwise, efforts will focus on majority groups and issues.

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2.3 | CT and teacher education

Supporting teacher learning about equitable teaching is essential for achieving equity goals, yet most of the literature focuses on student outcomes, especially in the field of CT and STEM integration (Wang et al., 2022). In addition to challenges supporting teacher learning about equitable practice and culture, there are challenges supporting teacher learning about computer science and CT. For example, Tofel-Grehl and colleagues have successfully integrated e-textiles to support culturally responsive computing (reviewed above), but they encountered challenges when preparing teachers to implement this in their classrooms (Tofel-Grehl et al., 2018). During their professional development, they found that teachers struggled with coding and were overwhelmed by merely reading and understanding code (Tofel-Grehl et al., 2018). As a response, they developed a faded scaffolding approach that supported teacher learning about coding.

Teachers are not prepared to teach CT or integrate CT with science in their teacher education programs, and there are few resources available to support this learning (Aljowaed & Alebaikan, 2018; Kite & Park, 2020; Sands et al., 2018; Wu et al., 2018). The lack of support and resources leads to low self-efficacy in regards to teaching CT and integrating it with science (Aljowaed & Alebaikan, 2018; Rich et al., 2021). The literature about supporting teacher integration of CT and science is growing. Some have used interventions to help preservice teachers learn about CT (Yadav et al., 2014; Yadav et al., 2017). Others, including ourselves in our prior work, have developed professional development programs to support teacher learning about CT and how to integrate it into science (Cabrera et al., 2024; Coenraad et al., 2022; Hestness et al., 2018; Kelter et al., 2021; Kite & Park, 2024; Peters-Burton et al., 2023; Wu et al., 2022). While these programs have been successful, more work is needed to fully understand how to support teachers with integrating and teaching CT in diverse contexts (Angeli & Giannakos, 2020; Barr & Stephenson, 2011; Wang et al., 2022; Yadav et al., 2014, 2017).

2.3.1 | Summary

Research shows that minoritized students have less access to CT learning and also experience push-out when opportunities are available (e.g., Fisher & Margolis, 2002). As such, it is important to use equitable teaching practices to support all students so they can equitably participate in CT-integrated science learning. The literature reviewed in this section highlights that most research on equitable participation in this space is primarily focused on student measures and does not outline curricular and instructional practices to foster equitable participation in classrooms. Additionally, a recent review of CT in STEM education found that very few research programs investigated pedagogical CT-integrated design or how it could improve equity (Wang et al., 2022). Although teachers and their pedagogical strategies are essential for supporting equitable participation, the literature is lacking in how to support teacher learning to promote equitable CT and science learning. This work attempts to begin addressing this gap by focusing on teachers' design of a CT-integrated science lesson. We investigate their design decisions to form an understanding of how CT-science teachers design to support equitable participation for their students.

2.4 | Prior work

In our previous work, we worked with science teachers to infuse CT practices and tools in existing curricula and classroom practices (Bain & Wilensky, 2020; Dabholkar et al., 2020; Levy

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et al., 2021). In this co-design work, our teachers collaboratively designed and implemented CT and science units. At the end of co-design, our teachers were able to integrate CT and science and were able to teach integrated CT and science. This work increased access to CT learning and impacted over 3000 students.

Although our project reaches a diverse set of students, our data does not indicate that our curricula provide equitable participation in the CT-integrated science classroom. Previous work in a class composed of 74% self-identified Hispanic or Latino students showed significant decreases in both interest in pursuing STEM fields with computing and enjoyment in CT practices after participation in a CT-integrated environmental science unit (Zhao et al., 2022). Further, when looking at responses by gender, the students who had positive experiences with the CT-integrated unit and interest in pursuing careers that use computational tools were largely male. This shows that our work, while reaching marginalized groups of students and increasing access to CT tools and practices, does not guarantee equitable participation in those practices. To ensure that all students are engaging in the curricula in rigorous ways that support the development of positive computing and science experiences, CT-integrated curricula must be designed to support equitable participation in the classroom.

Very little literature to date has attempted to understand how teachers, the designers and facilitators of CT-integrated learning environments, think about or approach equitable participation in CT-integrated curricula (Wang et al., 2022). "One area that needs immediate action is to design and research different instructional strategies, among other means, that promote equitable learning when integrating CT in STEM fields" (Wang et al., 2022). Fostering equitable participation in CT-integrated learning environments requires teachers to have an understanding of what it means and looks like in their classroom. In order to support teachers, we must have a better understanding of teachers' conceptions of equitable participation in CT-integrated learning. This study aims to address this gap by presenting teacher understandings of equitable participation in the context of CT-integrated curricula and by proposing a methodology through which such teacher understandings can be studied by researchers and practitioners.

3 | FRAMEWORK

This work is framed by engagement in constructionist co-design, in which teachers and researchers co-create curricular materials to facilitate the co-construction of professional knowledge and classroom materials (Levy et al., 2021). Our prior work focused on integrating CT with science and mathematics (Wu et al., 2022) through co-design from 2019 to 2022. This prior work built a co-design community that we leveraged for thinking about equitable participation in the work described in this article. Co-design refers to the collaboration between teachers and researchers to develop CT-infused STEM curricula (Penuel et al., 2007; Voogt et al., 2015); while teachers contribute knowledge on curricula, pedagogy, and student engagement, researchers contribute knowledge on CT tools and practices (Dabholkar et al., 2020; Levy et al., 2021; Wu et al., 2022). As Wu et al. (2020) describe, the purpose of co-design is twofold: from the co-design process, teachers gain an understanding of CT and become empowered teachers to redesign their curricula through incorporation of CT tools and practices. Constructionism is the theory that describes learning through the creation of a publicly shareable artifact (Papert & Harel, 1991). As people construct their artifact, they make design decisions and construct knowledge about the artifact. When teachers engage in co-design with researchers, they construct CT-integrated lessons and learn about CT in the process (Kelter et al., 2021).

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Additionally, teacher beliefs impact their curriculum design and the amount of time they put into modifying and teaching the curriculum (Cheung & Wong, 2002; Ennis, 1992). As such, this project leveraged curricular co-design to better understand teacher beliefs about equity in CT-integrated science curricula.

This work leveraged constructionist co-design relationships from prior work with teachers to explore how teachers support student equitable participation by modifying a CT-infused science lesson. In this article, the co-modification of an introductory lesson from our past work to support student equitable participation provided a constructionist co-design experience that allowed for characterization of teachers' conceptualizations of equitable participation and how their conceptualizations were put into practice through curricular modifications. Additionally, this work resulted in modified CT integrated with science lessons designed to support student equitable participation that are ready for implementation in teacher partners' classrooms.

4 | METHODS

This is a qualitative study that investigates teachers' conceptualizations and how they design for equitable participation through co-design of a CT-integrated science lesson. As part of this study, teachers modified an existing lesson that is used to introduce students to CT in science, which we refer to as "Lesson 0." We used modifications to Lesson 0 to understand teachers' ideas about equitable participation in the CT-integrated science classroom. In the following sections, we describe the participants and study setting, outline the primary data sources for our study, and explain the data analysis process. Our research aimed to answer the following two questions:

1. What are teachers' conceptualizations of equitable participation?
2. How do teachers design for equitable participation through co-design of a CT-integrated unit?

We leveraged a multiple case study approach (Yin, 2009). By creating individual cases for each teacher, we were able to draw insights at the teacher level as well as across cases.

4.1 | Participants and setting

Three researchers and four teachers participated in this study. The participating teachers taught in both urban and suburban high schools in the Midwestern United States. School demographics can be found in Table 1. The teacher cohort included two high school biology teachers (pseudonyms: Kate and Sarah), one high school environmental science teacher (pseudonyms: Lori), and one high school data science teacher (pseudonym: Jason). Additional teacher and researcher demographics are included in Table 2. When asked about their experiences learning about equity and equitable participation in the classroom, no teachers described having formal instruction on equity from their teacher education, however all four noted previously participating in at least one professional development workshop hosted by their schools on equity.

Teachers were recruited for this study to investigate how teachers conceptualized equitable participation in their STEM classrooms as well as how they made design decisions in their curricula in pursuit of equitable participation. Our research team had previously worked to co-

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TABLE 1 Demographics of the schools.

School	Teacher(s)	Race demographics	Free/reduced price lunch	Individualized education plans	English language learners
Evergreen High School	Jason, Kate	45.8% White, 26% Black, 18.7% Hispanic, 5.8% Asian, 3.3% Multi-racial	34.7%	11%	5.1%
Lakeview High School	Lori	3% White, 69% Black, 25.8% Hispanic, 0.8% Asian, 0.4% Multi-racial	62.5%	5%	2.3%
Sycamore High School	Sarah	5.5% White, 8.8% Black, 82% Hispanic, 1.8% Asian, 1.1% Multi-racial	89.9%	21%	24.3%

TABLE 2 Teacher and researcher demographics.

Team member	Demographics
Researchers	White woman
	South Asian (brown) man
	East Asian woman
Teachers	White man
	White woman
	White woman
	White woman

design CT-integrated curriculum with teachers in the Midwestern United States through a program called CT-STEM. CT-STEM sets the groundwork for co-design experiences and creates a co-design community. In pursuing our study on equitable participation, we leveraged this co-design community to identify teachers who were interested in helping to build off of the work they began in CT-STEM. In CT-STEM, they made curricula CT-infused, but in this study, we gave them a CT-infused lesson, Lesson 0, to modify for the explicit purpose of making it more equitable. All four teachers were recruited for our project because they had at least 1 year of co-design experience. It was important to leverage teachers who belonged to our co-design community because we wanted teachers who had experience with CT-integrated science curriculum in order to be able to effectively modify Lesson 0 with an eye toward equitable participation.

We did not provide any professional learning on equitable participation, but rather used this research to understand teachers' baseline conceptualizations of equitable participation. Researchers first conducted informal pre-interviews with participants to surface their conceptualizations of equitable participation. After conducting initial interviews with each teacher, teachers and researchers engaged in four weekly co-design sessions via Zoom over the course of 1 month. The target outcome of these co-design sessions was for each teacher to modify Lesson 0 to support equitable participation in the science classroom. Lesson 0 is an introductory lesson to integrated CT practices, with an emphasis on computational modeling practices. These practices include using, modifying, and debugging a series of computational models that

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simulate the spread of forest fires using NetLogo, a multi-agent programmable modeling environment (http://tinyurl.com/netlogofire; Wilensky, 1997; Wilensky, 1999). Our rationale for selecting Lesson 0 as the focus of co-design is twofold. The first reason we selected Lesson 0 is because all four of the teacher participants were introduced to CT using Lesson 0 as part of a previous professional development engagement. Feedback showed that teachers viewed this lesson as a good introduction to CT and modeling. The second reason is that these teachers added Lesson 0 to their instruction in the previous school year to introduce students to CT and modeling practices. Since students often initially struggle with CT, our belief is that their first encounter with CT practices should be as positive as possible. Therefore, we must start with an introductory lesson that foregrounds equitable participation. Knowing that the teachers approved of the content from a CT-integration perspective, this allowed us to understand their modifications from an equitable participation perspective. For these reasons, we asked teachers to produce one-modified Lesson 0 at the end of our four co-design workshops.

The four co-design sessions included discussion and feedback on Lesson 0 modifications from both teachers and researchers (see Table S3 for a detailed overview of co-design sections). Each session was 1 h in length. In between sessions, teachers worked asynchronously on revisions to their Lesson 0 and provided feedback to their assigned feedback partner (teacher partners were Jason and Lori and Kate and Sarah). Teachers tracked their work by writing design memos which included questions designed to support the co-design process and capture data about the modification process (see sample design memo in Figure 1). These co-design sessions provided an opportunity for teachers to offer each other feedback on modifications to Lesson 0 accomplished in between sessions. Researchers did not aim to impart opinions regarding equitable participation and did not provide any explicit instruction to teachers about equitable participation in the CT-integrated science classroom. In fact, none of the co-design sessions featured any lessons led by researchers on equity or equitable participation for teachers. The aim of these sessions, as exemplified by the structure of the co-design sessions, was to facilitate

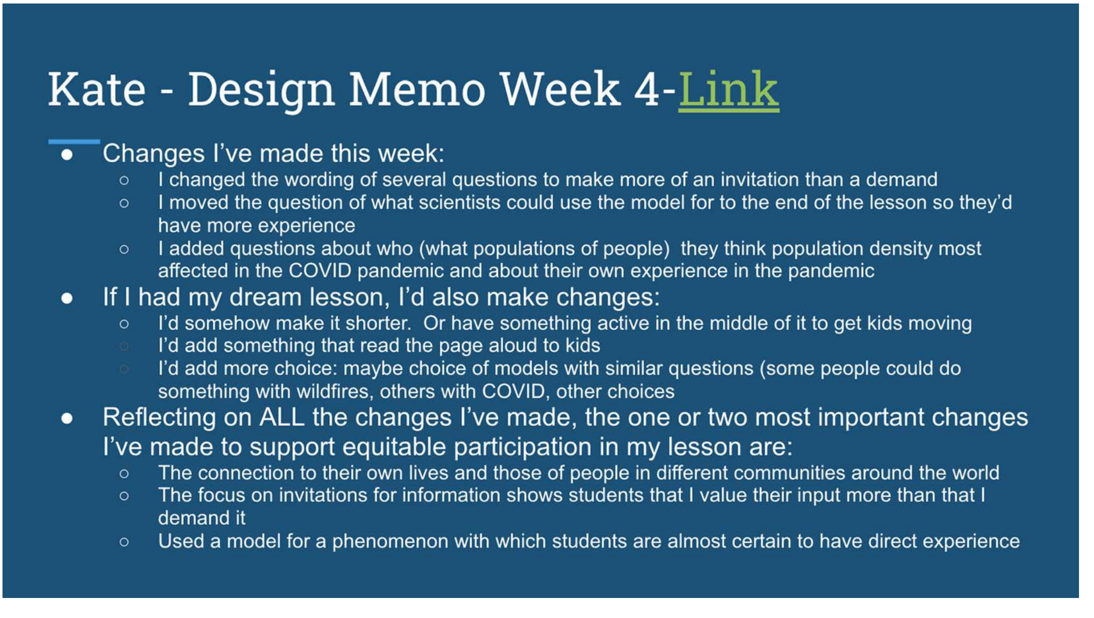

FIGURE 1 Sample design memo.

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discussion between teachers as they modified Lesson 0. At the end of these four co-design sessions, each teacher had produced one modified Lesson 0.

Following all four co-design sessions, researchers conducted a semi-structured post-interview. These interviews were designed to capture teachers' reasoning for the modifications they made to a CT-integrated unit. Taken together, our data allow us to analyze how teachers conceptualized equitable participation in their classrooms, document concrete curricular changes they made in pursuit of equitable participation, and explore the relationship between teachers' conceptualizations and how they design for equitable participation.

4.2 | Data sources and collection

Our primary data sources for this study include four pre-interviews, four post-interviews, four teacher design memos, and four modified Lesson 0s. The primary focus of our analysis are the teacher pre- and post-interviews and specific modifications to Lesson 0. The teacher interviews provide insight into both how teachers understand equitable participation as well as their rationale for making certain design choices in Lesson 0. The final modified Lesson 0 artifacts allow us to examine the curricular changes teachers made to Lesson 0.

4.2.1 | Pre-interview

One researcher conducted informal, 20-min interviews over Zoom with each teacher participant. Four pre-interviews were conducted. The goal of these interviews was to get an understanding of teacher conceptualizations, or expressed ideas, of equitable participation in CT-integrated learning. Interview questions were designed to elicit responses about teacher experiences with CT-integrated learning, understandings of equity, pedagogical tools to support equity in the classroom, and interest in collaborating with researchers on this project. Table S1 shows a list of the guiding questions used in these initial interviews. All interviews were recorded, transcribed, and coded.

4.2.2 | Teacher design memos

In between co-design meetings, teachers wrote design memos to track their changes to Lesson 0. Teachers answered questions to support the co-design process and capture data about their modifications as they made them to Lesson 0. The final memos listed the modifications the teachers made to Lesson 0 that they felt were most important. These identified modifications were used to guide our discussion about teacher modifications.

4.2.3 | Post-interview

After the co-design workshops, a post-interview was conducted for each teacher within 1 week of the final design session. The goal of these artifact-based semi-structured interviews (Fenwick et al., 2011) was to understand teacher conceptions of equity in CT-integrated curricula, revisions to Lesson 0 and their rationale for these revisions, and their experience in co-design sessions.

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Specific interview questions were tailored to the individual experiences of each teacher during the design workshops in order to allow teachers to generate concrete answers regarding their experiences throughout the study (see Table S2). For example, we asked teachers questions regarding their specific modifications to Lesson 0. Follow up questions were then used to further probe about equitable participation and identity. All interviews were recorded, transcribed, and coded.

4.3 | Data analysis

We used a multiple case study approach (Yin, 2009) to understand how four high school teachers made sense of equitable participation in the CT-integrated classroom by analyzing both their conceptualizations of equitable participation and their modifications to Lesson 0. Given that each teacher had a different classroom setting, a multiple case study approach allowed us to create a bounded case for each participant and compare across their cases for broader trends. Conceptualizations of equitable participation refer to teachers' expressed ideas about and experiences with equitable participation in the CT-integrated classroom. Modifications and design choices refer to the specific modifications to Lesson 0 made by teachers for the stated purpose of equitable participation in CT-integrated learning.

We conducted qualitative analysis of pre-interview and post-interview transcripts to understand how teachers conceptualized their ideas about equitable participation in the context of classroom teaching and made modifications to Lesson 0 in pursuit of equitable participation. Four researchers engaged in typological qualitative coding using conceptualizations and modifications as initial codes (Hatch, 2002). Codes, definitions, and examples can be found in Table 3. Researchers coded utterances in pre-interview and post-interview transcripts as conceptualizations or modifications. Researchers individually coded the same interview sample using conceptualization and modification codes and then all researchers discussed their codes to come to an agreement on the coding scheme. Individual researchers coded the remaining teacher interviews.

Using qualitative memoing to track our thoughts, researchers developed one case study per teacher that included both their conceptualizations, or expressed ideas, of equitable participation as well as their design choices in modifying Lesson 0 (Huberman et al., 2013; Saldaña, 2013; Yin, 2009). One researcher read through all teacher conceptualizations and teacher design memos to match each modification to Lesson 0 with a conceptualization from that teacher. The researchers triangulated the modifications with memos and pre- and post-interviews. The final combination of conceptualizations and design modification of Lesson 0 made up one case study per teacher. For cross teacher comparisons, similarities and differences across teachers were characterized as a summary of the cases. Findings were discussed to ensure agreement.

4.4 | Researcher positionality

The research team was composed of two white women (Authors 1 and 2), one white man (Author 4), and one woman of color (Author 3). Our methodology was designed to incorporate multiple perspectives and incorporated opportunities for feedback on interpretations. We acknowledge that our lived experiences are each different and impact how we interacted in this study and how we interpreted the data. Given that all researchers were affiliated with a higher education academic institution that currently and historically represents the ethnic and racial majority in the United States, our research practice is likely impacted by this context. We

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TABLE 3 Codebook.

Code	Description	Examples
Conceptualizations	Expressed ideas surrounding equitable participation "What I think equity means for a classroom context"	Phase 1 interview, Jason: *We felt like, especially in the math department that the equity and social justice lens was missing a lot in our curriculum as a whole. We found it was harder to bring it up in an authentic way without students or parents or Community members feeling like we were just checking the box, you know, like Oh, we did something that was. You know that seems like we were trying to appeal to non white students, and so we you know we checked that box, we did that okay now let's carry on with the rest of our typical math curriculum.* Phase 1 interview, Lori: *I think representation like identity is a big one, but it's not the only one. Also making sure it's accommodating to diverse needs like English language learners is another huge piece of equity. You know, differences like lived experiences and place based education would fall under equity for me. And, just like God kind of like the relevancy piece I think fault and to equity bucket.*
Modifications	Concrete curricular design and pedagogical practice to support equitable participation in co-design CT-integrated lesson modifications "What I do and how I do it"	Phase 2 interview, Lori: *I think for students and for teachers that aren't used to using modeling as a practice and then more with like the relevancy piece, I tried to bring in like real data.* Phase 2 interview, Jason: *you're saying okay discuss with others and it's not just pull them totally on their own, I always find that when I give students the opportunity to discuss with others, they're more likely to come up with really great responses, because they're more willing to share. You know they're talking to their friends, instead of talking to the teacher, and so I think those types of opportunities, where you allow students to collaborate and let them let their voices be heard in the classroom.*

recognize that our experiences have privilege and may not represent the views and experiences of minoritized student populations. The methodology of collaborative coding and code checking was adopted by the research team in an attempt to confront potential biases throughout the data analysis process. Our combined interest in promoting equitable participation in these contexts drove us to complete this work and impacted our qualitative noticings and the types of codes we developed from the interview data. Understandings of equitable participation and the interpretations of interview data will likely vary with a different set of participants and researchers.

5 | FINDINGS

The findings section presents four teacher case studies. For each teacher, we describe their conceptualizations, or expressed ideas, of equitable participation. We also describe the concrete

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curricular changes teachers made to Lesson 0 in pursuit of equitable participation and teacher's expressed rationale for these changes. For the scope of this study, we have limited our discussion to three modifications per teacher, which they identified as being the most important changes to Lesson 0 in their final design memo. We close the findings section with a cross-teacher comparison.

5.1 | Kate

Kate is a biology teacher at a suburban high school outside of a large Midwestern city. Prior to participating in co-design workshops, she described the importance of fostering a sense of belonging and engagement in the science classroom. She stated, “I want my students to feel that their experiences are important and valid and [that] I'm valuable to me and to our classroom community” (Kate, Pre-Interview). This shows that providing an environment that fosters a student's sense of belonging is important in her biology classroom. In our pre-interview, she described one activity that she had previously used to foster student belonging was having students present to the class on a scientist that they share something in common with. For example, a student who spoke Tagalog gave a presentation about a scientist who spoke Tagolog. She notes, “Students really responded to being able to see both the diversity in background, like in racial and ethnic background, but also in interests, so they could be like, oh, I can really see myself in that” (Kate, Pre-Interview). By using this activity, Kate encourages students to draw connections between professional scientists and student identity. In doing so, she aims to foster a sense of student engagement and belonging in the science classroom.

Kate's modifications to Lesson 0 focused on making the computational model more relevant and increasing student choice and agency through pedagogical strategies. The modification she listed as the most important was changing the forest fire computational model in Lesson 0 to model the spread of the COVID-19 virus (see Figure 2). While she was confident all of her students had experienced the spread of COVID, she was not sure how many of her students had any real-life experience with forest fires, since they were located near a large Midwestern city. While reflecting on this design choice, she stated, “I know that my students are coming from wildly different experiences, so the biggest thing that I wanted to do was make [the model] something that everyone in the world at this point could relate to” (Kate, Post-Interview). To that end, she viewed the relevancy of the COVID transmission model as a means of increasing student engagement in CT practices. Moreover, she identified the COVID model as a “place where students could be invited in [to the curriculum]” (Kate, Post-Interview). By this, she posits the computational model as an opportunity to increase student engagement in the lesson by fostering a sense of relevancy.

Another modification she cited as important was adding questions about the impact of COVID and population density. She added a question to Lesson 0 asking students to describe how population density might impact how differences in COVID spread across the United States (see Figure 3). As she explained, the purpose of these questions is to get learners to “see like in [school city] where people are more quite closely packed, there's higher there has been higher spread” (Kate, Post-Interview). By using place-based relevancy, this provided students with an opportunity to draw a direct connection between a scientific phenomenon, population density, expressed through a computational model. She noted, “I think sometimes some of these models can feel really abstract unless they are personalized, and then it's just easier to lose students if they're not personally invested” (Kate, Post-Interview). Thus, Kate wanted to

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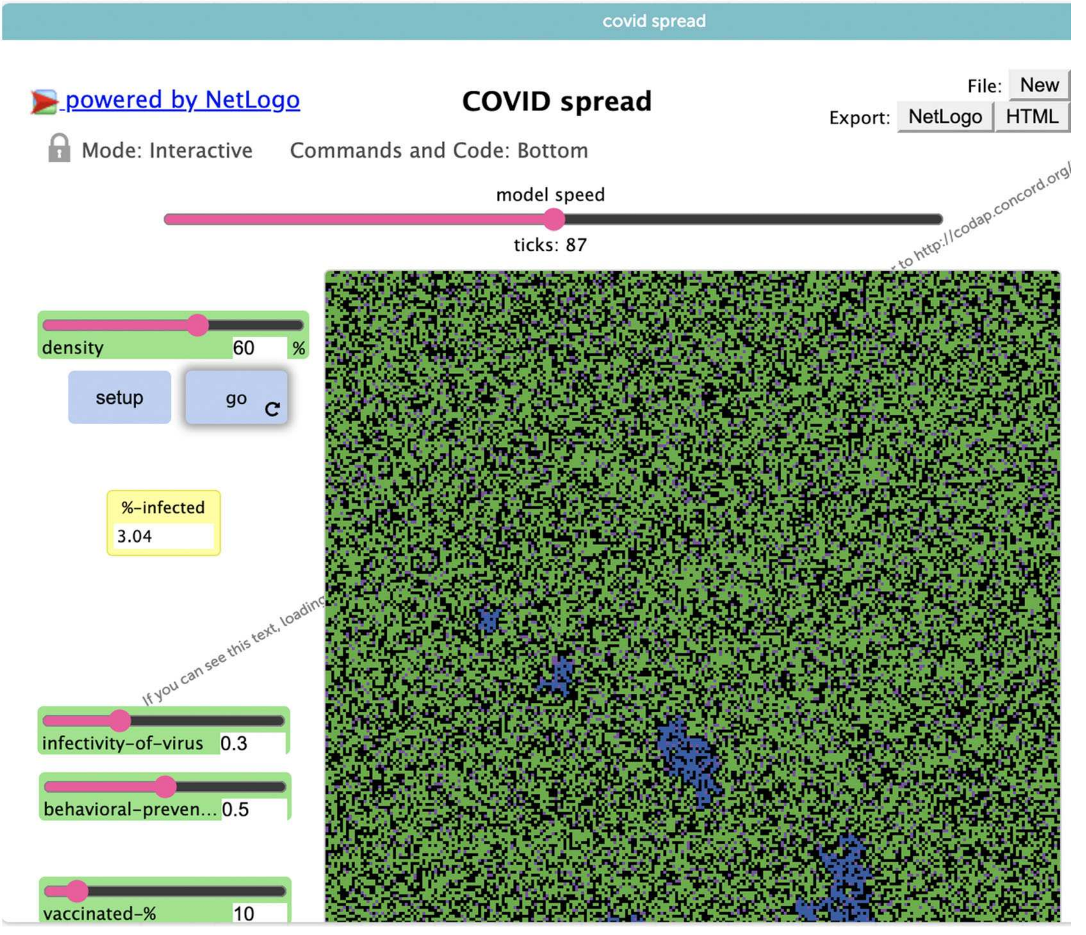

FIGURE 2 Modification: Students practice computational modeling practices with a COVID model.

prompt students to draw connections between the scientific concept and their hometown. By promoting a sense of relevance, Kate aimed to increase student engagement in Lesson 0, which aligned with her conceptualization of equitable participation.

Additionally, Kate incorporated an activity in which science students designed their own experiments. She asked students to brainstorm experimental questions that could be tested by the computational model, develop a hypothesis, and design an experimental procedure (see Figure 4). When describing this design choice, she explained, “I made the last page something they had more of a choice in designing their experiment, so that it would be something that they were more interested in” (Kate, Post-Interview). By allowing students to exercise choice and agency in Lesson 0, she believed that students would feel more interested in engaging with the computational model. She stated, “I think when people feel like they have a choice, they're more likely to engage” (Kate, Post-Interview). Similar to her other modifications, the addition of the experiment design reflects Kate's desire to increase student engagement in the lesson.

These three modifications to Lesson 0 align with her initial conceptualization of equitable participation as providing opportunities for students to engage with and feel connected to science. Specifically, her modifications aim to support connections to students' identities through

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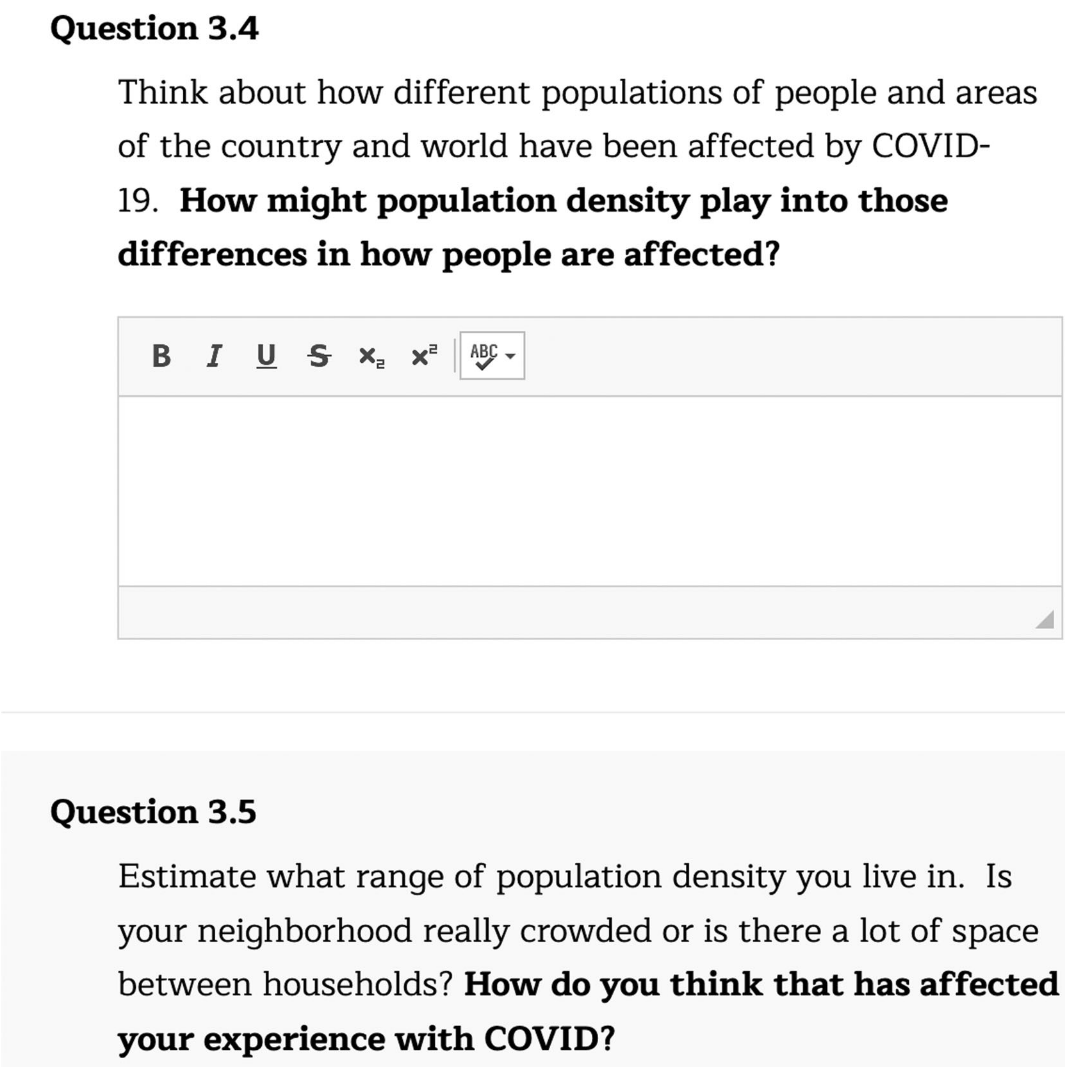

FIGURE 3 Modification: Students explore the relationship between COVID and population density.

relevance. Kate changed the computational model from a forest fire to COVID disease transmission. In doing so, she focused on leveraging personal experiences via a context that all students would relate to. She also connected to students' interests by allowing them to design their own experiments. This shows that Kate's modifications to Lesson 0 reflect her understanding of equitable participation in the science classroom as fostering a sense of belonging and inclusion.

5.2 | Jason

Jason is a data science teacher at a suburban high school outside of a large Midwestern city. Prior to participating in co-design workshops, he discussed supporting equitable participation in the data science classroom by challenging classroom power structures. Jason acknowledged his identity as a white male teacher and his desire to relate to his students. He stated, "As a

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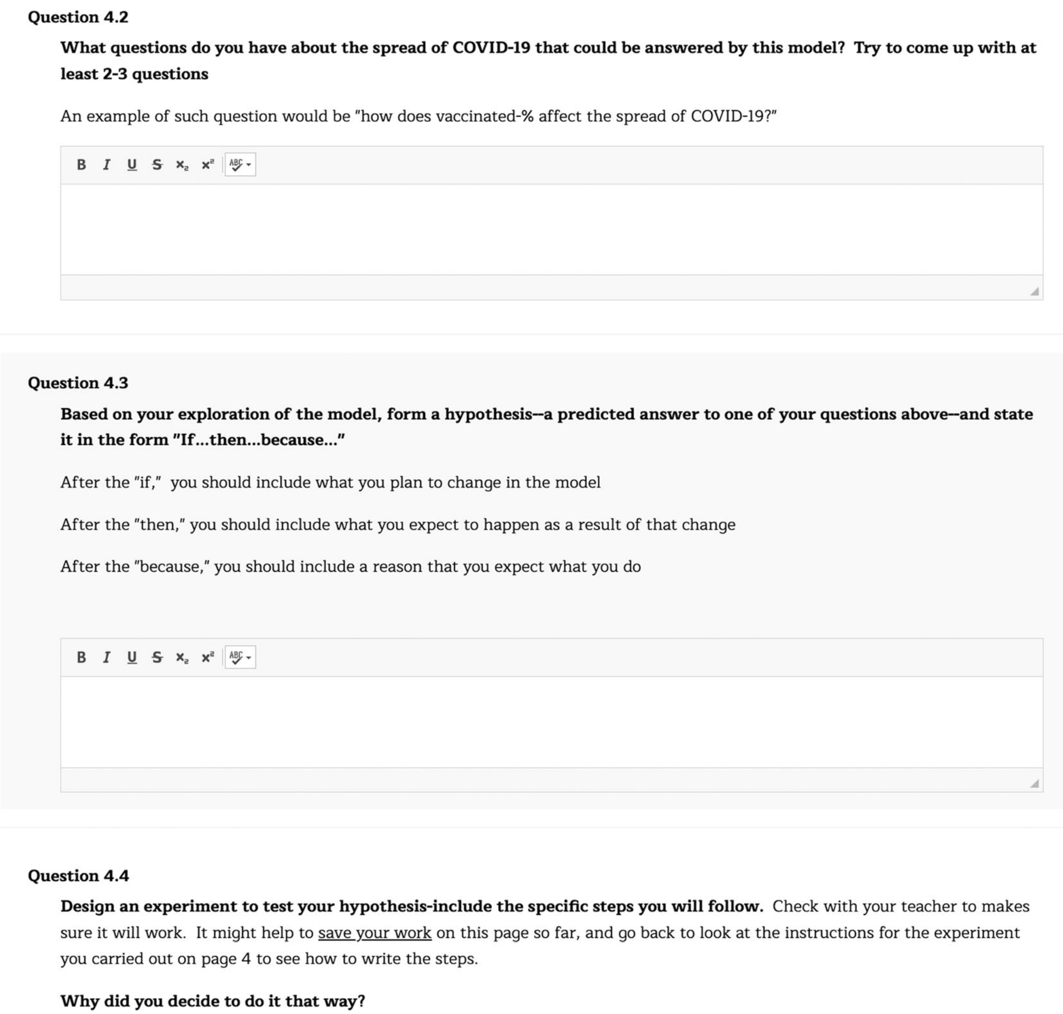

FIGURE 4 Modification: Students design their own experiments.

white male teacher … I'm always trying to figure out what I can do to present the curriculum in a more engaging way" (Jason, Pre-Interview). He connected this understanding to a broader, school-wide initiative to create a more equitable and inclusive institution overall. He stated:

> If you're part of the majority, then it's your job to be educated on these topics, and [my school] teaches us to look at our practices as an educator through an equitable lens and an anti-racist lens and being a social justice warrior. (Jason, Pre-Interview)

This shows that, going into co-design workshops, Jason believed that an understanding of teacher identity and classroom power dynamics was crucial to designing for equitable participation in the data science classroom.

When redesigning Lesson 0, Jason made design choices with Black male focal students in mind. He adopted this framework of using a focal student from an ongoing initiative at his high

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school. He noted, “At [my school] we said that this school year was the year of the Black male [...] what I can do to make my lessons applicable, relevant, and engaging to them is important” (Jason, Post-Interview). He made modifications to Lesson 0 with this particular group of students in mind. His modifications included addition of discussions, attention to careers, shifting the focus of the lesson from science to data science, and making data science relevant.

The most important modification to Lesson 0, as noted in his design memo, was adding in partner and small group discussions. Jason added text such as, “Discuss with a partner and list your examples below” to prompt classroom discussion throughout Lesson 0 (see Figure 5). Jason viewed student collaboration and discussion as a way to shift the dominant classroom voice from his voice, as the teacher, to his student's voices, specifically his focal students. He explained, “I think that sometimes their voice gets lost in the classroom as a person of color, and so I wanted to make sure that I wasn't the voice dominating the room as a white male” (Jason, Post-Interview). Therefore, the choice to incorporate more opportunities for student discussion connects directly to Jason's goal to promote equitable participation by challenging traditional classroom dynamics. Further, he shared, “When you give them opportunities to discuss with a partner and share their thinking, I think that gives them the platform to take control of their own learning” (Jason, Post-Interview). This demonstrates that he also viewed this modification as a way of introducing student agency into the Lesson 0 learning experience.

Another modification Jason identified was adding questions and discussions about science careers. He added a question stating, “Can you think of some careers where someone may use computational modeling, CT and/or computational visualization tools?” (see Figure 6). Jason added this question to prompt students to connect the CT skills they learned about in Lesson 0 with ideas for future careers in the science field. He stated, “I'm always trying to push them toward using statistics more in their future lives” (Jason, Post-Interview). This design choice encourages students to connect CT ideas and practices to their own futures.

Additionally, Jason made changes to Lesson 0 that made data science more tangible, including the addition of a Galton Board (see Figure 7). A Galton Board is a device for statistical experiments and visualizing the concept of normal distribution. While adding this content, Jason focused on making data science more tangible and meaningful for his focal students. He stated, “[M]y students want to know why is this relevant in their daily lives ... I think that's that Galton Board example was a thing that I've shown students” (Jason, Post-Interview). To that end, Jason used the Galton Board model in order to demonstrate relevance in students' lives. He also added that, when adding the Galton Board to Lesson 0, “I was thinking through

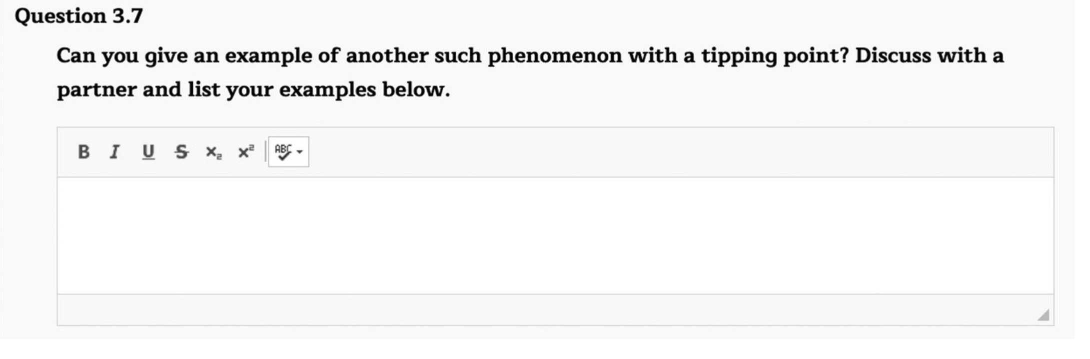

FIGURE 5 Modification: Students are prompted to collaborate with peers.

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Question 5.3

Can you think of some careers where someone may use computational modeling, computational thinking and/or computational visualization tools? **Discuss with a partner and list your ideas below.**

Enter your response

FIGURE 6 Modification: Students prompted to reflect on computational thinking in careers.

FIGURE 7 Students understand computational modeling through Galton Board example.

how to make that statistics tangible and relevant to my students of color" (Jason, Post-Interview). Again Jason uses his focal students in order to reimagine and redesign Lesson 0 is such a way that will promote equitable participation. In his understanding, learning experiences in the data science classroom should be directly relevant to students, with a particular eye for Black male students, and should challenge typical classroom power dynamics.

In Lesson 0, Jason aimed to make the data science content more tangible for his students. To achieve this, Jason modified many of the questions to support statistical ideas. He viewed this as making Lesson 0 more relevant to his data science students. Another one of his primary goals was to engage his Black male students in data science in meaningful ways, which was exemplified through the addition of small group discussions to elevate their voices in the classroom and shift traditional classroom power dynamics.

5.3 | Sarah

Sarah is a special education biology teacher whose conceptualization of equitable participation centered the diverse learning needs of her special education biology students. She emphasized

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the importance of considering "where you function intellectually," framing the bounds of this spectrum as "gifted or SPED [Special Education]" (Sarah, Post-Interview). For Sarah, equitable participation meant "everybody gets what they need" (Sarah, Post-Interview). To her, this meant science lessons should be designed with the unique learning needs of each student in mind so that each may participate. For example, she discussed one of her students who struggles with understanding facial expressions and discerning meaning from words in conversation. She noted, "It is hard for him to understand what people mean. He doesn't pick up facial expressions" (Sarah, Post-Interview). Including learning needs related to decoding facial expressions and visual perception was part of her understanding of equitable participation in the science classroom. Similarly, she shared:

> I think of kids who can't read only because they struggle with figure-ground discrimination, where black letters on white paper are hard to understand. It would be great if we could adjust colors. All kids could take advantage of that. (Sarah, P2 Interview)

In this case, Sarah positioned visual processing needs as important to design around so that students can participate in learning despite differences in how their brains process visual information.

Sarah's population of science learners impacted both her conceptualizations of equitable participation and design choices and modifications to Lesson 0. As a SPED science teacher, Sarah recognized that students often feel overwhelmed by large amounts of text that often include complex tasks and questions. Listed in her design memo as the most important modification to Lesson 0, Sarah split complex questions and activities into smaller tasks and questions (see Figure 8). She explained, "I split up some of these questions because they were all kind of stuck together and my experience with special education kids is [they] become overwhelmed and [they] can't answer more than one question at a time" (Sarah, Post-Interview). To address this barrier to engaging with the lesson, Sarah split questions and tasks into smaller, more manageable pieces. She also made it apparent which pieces of texts the students were asked to respond to by bolding and highlighting particular phrases.

Another key modification Sarah made was changing the term "bug" as utilized throughout Lesson 0 to "mistake." In the original Lesson 0, students were asked to find the "bug" in the code. Knowing her students, Sarah did not believe that her students would understand the meaning of the word bug in the context of Lesson 0. When describing a previous lesson that used the term bug, Sue said, "[The question] just said, 'What is the bug?' And we asked kids what these were. Do you know how many answers I got [saying] little black bugs? Okay, so I know better than to ask those kinds of questions" (Sarah, Post-Interview). Knowing her students and their diverse learning needs, Sarah made this modification so her students could understand and answer the questions related to debugging in Lesson 0. She also defined the meaning of the word bug in the text of the question (see Figure 9). This modification was made to help her students understand the question and to teach them a new word. Importantly, by defining this word for students, they were able to appropriately engage with the lesson—no matter how much experience they did or did not have with computing terminology.

Like Kate, Sarah changed the context of the computational model from forest fire spread to COVID spread. She changed this to make the model more relevant to students and to build relationships based on shared experiences. About the COVID model, she explained, "[The students] all have a story to share, so I think if you're going to get kids to start coding, if they can share an experience and then we're all kind of in the same boat" (Sarah, Post-Interview). She went on

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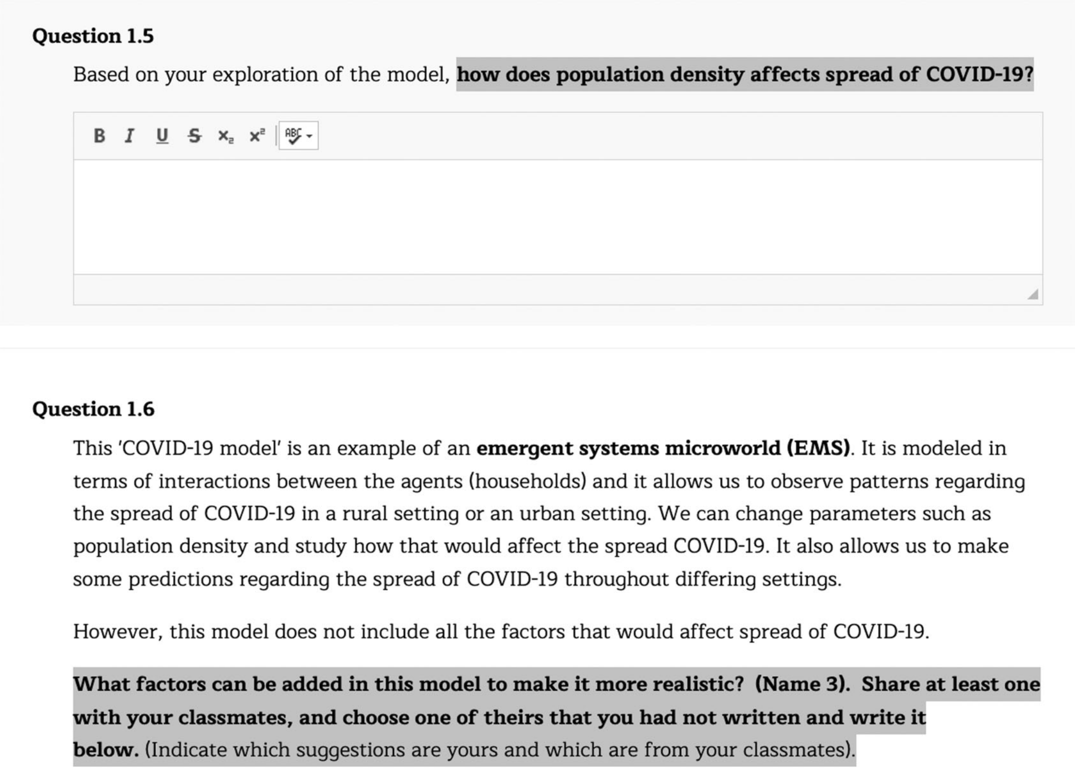


Question 1.5

Based on your exploration of the model, **how does population density affects spread of COVID-19?**

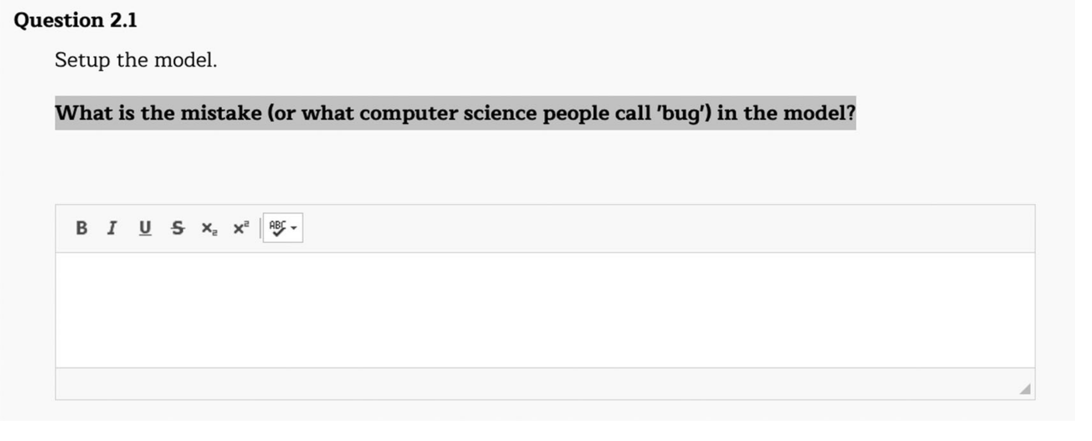
Question 1.6

This 'COVID-19 model' is an example of an **emergent systems microworld (EMS)**. It is modeled in terms of interactions between the agents (households) and it allows us to observe patterns regarding the spread of COVID-19 in a rural setting or an urban setting. We can change parameters such as population density and study how that would affect the spread COVID-19. It also allows us to make some predictions regarding the spread of COVID-19 throughout differing settings.

However, this model does not include all the factors that would affect spread of COVID-19.

What factors can be added in this model to make it more realistic? (Name 3). Share at least one with your classmates, and choose one of theirs that you had not written and write it below. (Indicate which suggestions are yours and which are from your classmates).

FIGURE 8 Modification: Students are clearly directed to scaffolded questions.



Question 2.1

Setup the model.

What is the mistake (or what computer science people call 'bug') in the model?

FIGURE 9 Students are provided with a definition of "bug."

to say, "You can build a relationship with this, you can get over their fear of coding because you've just built that relationship with them, and then you can start teaching them something" (Sarah, Post-Interview). Sarah believed that by providing an opportunity for students to engage with a computational model that provided an opportunity for students to directly connect with, she would be able to better engage students in CT learning.

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Sarah's primary objective in modifying Lesson 0 was to make a learning experience that was able to meet the needs of the diverse learners in her special education science classroom.

5.4 | Lori

Lori is an environmental science teacher at a high school in a large Midwestern city. Lori had a multifaceted view of equitable participation in her classroom. This included several ideas, which she discussed in her interviews, including increased representation and celebration of marginalized identities, instructional accommodations, and support for individual learning needs and preferences, and providing opportunities for place-based relevancy in lessons. She stated:

> I think representation, like identity, is a big one, but it's not the only one. Also making sure it's accommodating to diverse needs and English language learners is another huge piece of equity. Different lived experiences and place-based education would fall under equity for me. And, the relevancy piece I think falls into the equity bucket. (Lori, Pre-Interview)

Here, she names the various components she views when thinking about designing for more equitable learning experiences in the science classroom. She also described place-based relevancy as a reason for previous curricular design moves and instructional strategies. For example, she mentioned, "We've talked about it in class a lot in terms of [Midwestern city]. The study just came out that [Midwestern city] has the largest life expectancy gap in the nation" (Lori, Pre-Interview). This shows that Lori has used place-based relevancy in order to encourage her students to draw connections between science content and their communities.

Lori also believed it was important to accommodate students with varying needs, specifically noting students who are special education students and English language learners. She said, "For those students that are struggling or have very specific needs, it's a little easier to identify those and adjust for those whether they're special education students or ESL [English as a Second Language] students" (Lori, Post-Interview), Interestingly, she noted that, in some ways, it was easier to identify the particular accommodations and solutions in order to provide a more inclusive learning experience for these students. In contrast, however, she noted that it can be challenging to find a culturally relevant topic that resonates with all learners because students have different interests and backgrounds. She explained:

> If you have students that have various kinds of backgrounds, which you know, regardless of race or ethnicity or socioeconomic status, all of our students are unique individuals. And so it can be hard to always try and figure out what that cultural relevancy piece is that hits everybody. (Lori, Post-Interview)

While for some student needs, the solutions to increasing equitable participation seemed more apparent, other design choices were more challenging, such as finding topics that resonated with students across different needs and backgrounds.

Lori mentioned her focus on using real-life examples that relate both to students' interests and to the science content to help build meaningful connections. She discussed concepts that cut across various aspects of student identities as a way of drawing connections and creating moments for shared connection with students. Importantly, she believed that the basis of these

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connections were not surface-level, but rather demonstrated to students an understanding of them as people first. She stated:

> I think a lot of times equity work is so rooted in, 'How do you make it connect to the kids' interests?' […] We can't cater to every single person's interest, but we can use these big ideas that can hopefully elicit common experiences. (Lori, Post-Interview)

When conceptualizing equitable participation, Lori ultimately viewed student identity as an important way through which students can draw connections between science concepts and their own lives and experiences.

Lori's modifications to Lesson 0 primarily focused on relevancy and local connections. The most important modification she noted in her design memo was changing the atom model in the Lesson 0 introduction to snowfall accumulation. In the original Lesson 0, students were shown a static model of an atom to start a discussion about the different types of models in science. Lori changed the model to one that snowed snowfall accumulation because, living in a large Midwestern city, her students had experience with snow (see Figure 10). She said:

> Because in our region [snowfall is] something that everybody has seen […] it felt like an easy on-ramp to talking about models which are oftentimes kind of scary for students and for teachers that aren't used to using modeling as a practice. (Lori, Post-Interview)

In her explanation, Lori reveals that this modification provided an opportunity for the computational model used in the introduction of Lesson 0 to be more relevant to students in her

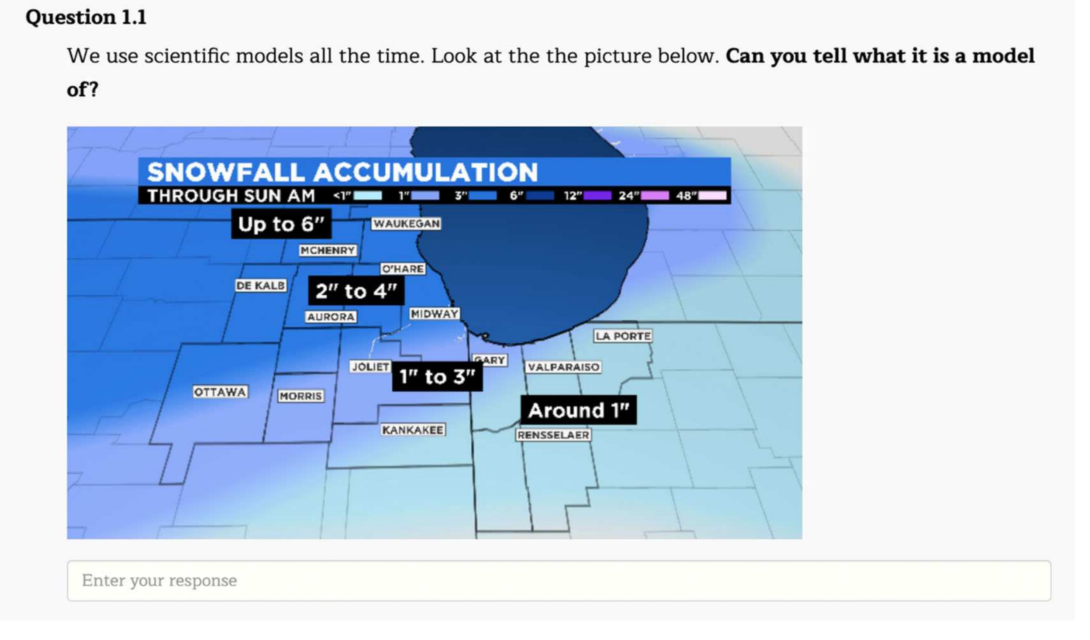

FIGURE 10 Modification: Students reference a model of snowfall accumulation.

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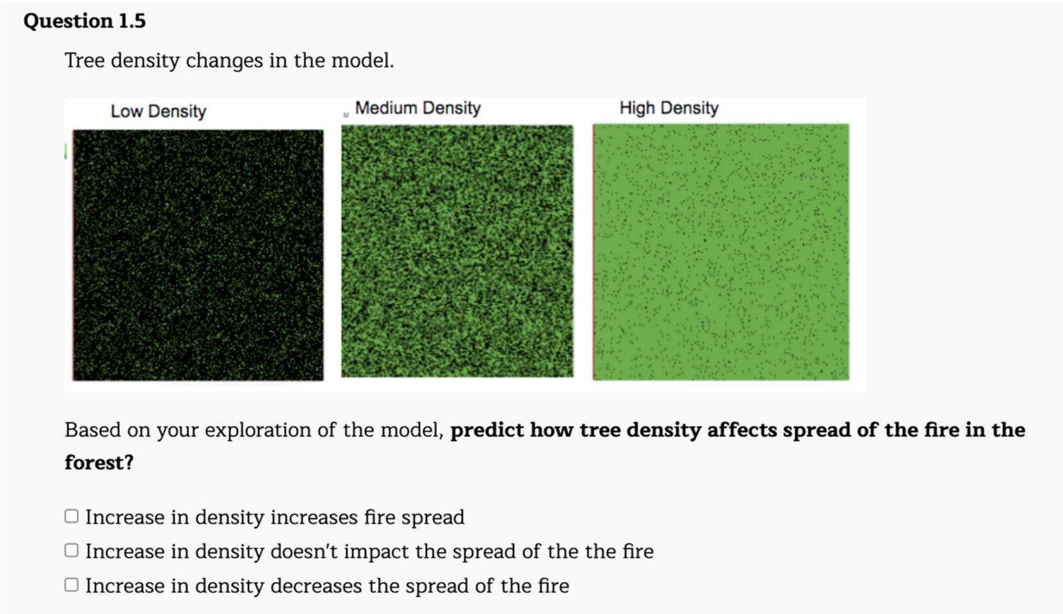

FIGURE 11 Modification: Students are provided with images representing density.

science classroom. Lori hoped to bring a familiar example of a model to provide a sense of comfort and relevancy into a potentially unfamiliar practice.

Additionally, Lori added images and visuals to better represent science topics throughout Lesson 0. For example, she added pictures of trees and forests to depict tree density that was represented as green squares in the computational model (see Figure 11). She explained:

> [The students] can kind of think about where there are more trees versus where there are fewer trees and then have the chance to bring back that research question and just make the idea of research with the model a little more relevant. (Lori, Post-Interview)

By incorporating more images, Lori's aim was to provide students with more of an understanding of the science concepts covered in Lesson 0.

Lori included cross-curricular questions in Lesson 0. She added in discussion questions that connected the CT and science content to other social aspects. For example, she added a question regarding tipping points, as shown in the snowfall model, being used to close schools during a snowstorm (see Figure 12). She explained, "I think it's a cool way to pull that cross-curricular piece in to think about there are reasons outside of science why things have happened, whether they are political or social or other things connected to our world" (Lori, Post-Interview). By adding in cross-curricular topics in Lesson 0, Lori wanted to encourage students to draw connections between science and CT content into their lives, making the content more relevant and meaningful.

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FIGURE 12 Modification: Students are asked to draw connections between CT and their world.

5.5 | Cross-teacher comparison

When comparing teachers' conceptualizations of equitable participation and modifications to Lesson 0, some similarities emerged across all teachers. Primarily, teachers were interested in making modifications to Lesson 0 that would increase accessibility to Lesson 0 content, foster inclusion in the science classroom, and make science and CT more relevant to students and their experiences. Both Kate and Sarah modified the original forest fire computational model to model COVID-19 transmission. Their utterances reflect a desire for students to connect

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meaningfully with Lesson 0 content. When describing this modification, Kate shared that she wanted to "[make] sure that there were multiple places [that] students could be invited in" (Kate, Post-Interview). This notion of inviting students' into Lesson 0 refers to the idea of making changes to the curricula such that students could better relate to—and thus understand—CT and science practices. Similarly, Sarah believed that by modifying the forest fire computational model to model the transmission of COVID she was providing an example of a science phenomenon that all her students could relate to. She said:

> When I'm making lessons and [thinking about] things that we should have in common, that we can all share. We've all been through COVID [...] through COVID in our own way, but we've all been through it. So I think this is a great way to do it. (Sarah, Post-Interview)

Like Kate, Sarah viewed the COVID model as an opportunity to provide students with a science phenomenon, as exemplified through a computational model, that they could all relate to. Their belief was that, in doing so, students would feel more connected and engaged in Lesson 0.

As reflected through different modifications, Lori and Jason, too, wanted to make Lesson 0 content more engaging for students. For instance, Lori replaced an atom model used in the introduction of Lesson 0 with a model of snowfall accumulation. She believed this modification would make computational modeling more relevant to her students because "in our region, right, that's something that everybody has seen" (Lori, Post-Interview). Using place-based relevancy, Lori made modifications to Lesson 0 that would make the computational model more approachable to students. Similarly, Jason modified content in Lesson 0 to make data science content more tangible. When explaining the modification to Lesson 0 to replace the forest fire computational model to a Galton Board, he described:

> I think that's that Galton Board example was a thing that I've shown students in class and I'm like, that's cool. I have some questions, let's talk about it, versus me going up to the board and saying, here's the central limit theorem and I can give the best possible explanation of the central limit theorem but sometimes for students, they want to like to see it and they want to feel it and, having those for them in the room provides a great discussion to say, okay here's what you can do with this like okay now you understand what this model is doing let's talk about why it's useful. (Jason, Post-Interview)

By modifying the lesson to include more data science content, Jason aimed to make Lesson 0 more relevant, and thus engaging, to his students. Modifications from all four teachers primarily focused on making Lesson 0 more accessible, inclusive, and relevant to their science students.

Teachers differed in their approaches to modifying Lesson 0. For example, while Jason tailored his modifications to one focal student group, Black male students, Sarah focused primarily on her science special education students. As such, their modifications have different functions; Jason focused on increasing opportunities for collaboration to challenge existing classroom power dynamics, and Sarah centered her modifications around accessibility with a particular emphasis on individual student cognitive needs. Interestingly though, despite serving as different functions in their respective classrooms, these modifications both broadly aim to support

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student CT-integrated science learning by providing more accessible and inclusive learning experiences. Moreover, while Jason and Sarah focused on tailoring modifications to students with specific identities, Lori did not use that as a strategy for making modifications. In fact, she stated:

> I think that was the other kind of like question I kept coming back to is like who is [Lesson 0] for. And it was hard for me to kind of nail down. I mean I could have picked like you know one person or something, but [...] I really went more from the relevancy and like local standpoint and being able for in terms of like the modifications like having kind of an easy on-ramp for the majority of people. (Lori, Post-Interview)

While Jason and Sarah found it useful to tailor modifications to focal students, Lori chose to take a more holistic approach by making modifications to Lesson 0 to be more region specific, like the snowfall accumulation model. Although differing in their approaches, teachers attempted to modify Lesson 0 to support equitable participation by focusing on accessibility, inclusion, and relevancy.

Although all four teachers made important modifications to promote equitable participation practices in Lesson 0, there are other modifications that could further support students. Some teachers explicitly reflected on their practice and acknowledged their continuing journey and commitment to learn more about supporting equity in their classrooms. Jason acknowledged that he was still unsure about his teaching practice in supporting equitable engagement and that he is growing and improving. In terms of the modifications he made to Lesson 0, he thought he could have done more, stating, "I don't think I did the best job of that in my unit. I think I could have made more drastic changes that addressed equity" (Jason, Post-Interview). Jason mentioned that he wanted to further foreground Black student voices in his teaching in the future. Lori also reflected on her progress and current work about equity and discussed her continuing work. She said, "I strive to be more equitable, but I wouldn't call [Lesson 0] a prime example of equity. Because I don't think I'm there and [...] I don't know if I've seen a good curriculum that I can say is like, oh, that's very equitable" (Lori, Post-Interview).

6 | DISCUSSION

Our findings suggest that teachers conceptualized and designed for equitable participation in the context of a CT-integrated curriculum across three primary dimensions: accessibility, inclusion, and relevancy. Teachers made modifications so that all of their science students could access the content. These modifications included changing vocabulary, adding glossaries, adding hints and scaffolds, and shortening sentences. These modifications align with approaches to designing curriculum for accessibility (Burgstahler, 2009). If students cannot access the activities and computational models, then they will be unable to engage equitably (Burgstahler, 2009). Teachers designed for inclusion so diverse students could engage comfortably in Lesson 0 to meaningfully participate in activities and lessons by adding opportunities for collaboration and discussion and bringing in stories from their own experiences. Collaborative learning through group discussions and activities supports student agency, interest, engagement, and learning (Baker et al., 2017; Boardman et al., 2015; Hänze & Berger, 2007). Incorporating opportunities for students to share stories from their own lives and experiences

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supports equitable participation because it provides opportunities to connect culture and science practice from outside of the classroom to inside the classroom (Barton & Yang, 2000; Searle et al., 2019; Tofel-Grehl et al., 2017). This promotes a broadening of traditional school science to include and value diverse experiences (Barton & Yang, 2000). Promoting inclusion is essential because it impacts students' sense of belonging in STEM, which impacts their STEM classroom engagement (Mulvey et al., 2022). Additionally, teachers wanted to make Lesson 0 relevant to students by connecting CT to class topics, students' experiences, and identities. Students engaged with computational models that directly impact their region and were encouraged to find shared experiences by engaging with CT practices and ideas. Connecting to students' experiences and lives aligns with literature about supporting diverse student science learning (Barton, 2003; Barton & Tan, 2010; Fischback et al., 2020). When learning is relevant to students, it becomes more meaningful and helps blend school science and their everyday lives (Barton & Tan, 2010). This aligns with recent findings in CT and science context where relevance promoted student outcomes, including empowerment with computational problem-solving (Krakowski et al., 2024). Overall, teacher modifications reflect the goal of creating a revised Lesson 0 that promotes more equitable participation in computational modeling in science.

Teachers exercise significant influence over the design and implementation of their lessons, meaning that their ways of thinking about the content of their instruction and preferred methods of implementation impact student learning activities and outcomes (Cheung & Wong, 2002; Ennis, 1992). As such, teachers' conceptualizations of equitable participation and how they design for it impact students' opportunities for equitable participation and learning. To study how to promote equitable participation in science classrooms, we must first understand how teachers conceptualize equitable participation and how they design it. Despite this, little is known about how teachers conceptualize or design for equitable participation in their classrooms and many teachers do not feel agency for advocating for equity in STEM education (Holincheck et al., 2024). Our work, in uncovering the three dimensions of accessibility, inclusion, and relevancy in teacher conceptualizations and design choices toward equitable participation, is an important step toward understanding how to design teacher learning opportunities that may lead to greater equitable participation for their students. We believe that, by empowering teachers to design for equitable participation and equity in the science classroom, we can create more equitable CT-integrated science learning experiences.

Within the growing field of researchers and practitioners interested in designing equitable learning environments, there are several ways to conceptualize equity in the science classroom (e.g., Ladson-Billings, 1995a; Ladson-Billings, 1995b; Ladson-Billings, 2004; Scott et al., 2015; Vakil, 2018; Wang et al., 2022). Our study also found evidence of this; for instance, Jason theorized participation in which students feel a shared sense of power and interest despite racial and ethnic differences, while Sarah foregrounded designing for her special education science students, with particular attention to individualized student needs. These different perspectives on equitable participation can create problems for both teachers and researchers; teachers are unable to design for equitable participation in their classrooms if they do not have a clear understanding of what equitable participation means. Similarly, researchers are unable to study equitable participation if they do not have a clear understanding of how teachers think about it in the first place. Knowing the different ways teachers think about equitable participation helps researchers to more accurately assess equitable participation in a CT and science integrated classroom. Ultimately, our goal is to achieve equitable participation in science classrooms, and it is important to understand teachers' conceptualizations of equitable participation first. Now

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that we know that our teacher partners bring these three lenses to equitable participation design, we can tailor future programming accordingly as discussed in Section 8. Moving forward, we must also study these design choices specifically to understand their efficacy by observing their implementation in the CT-integrated science classroom.

Finally, our work suggests that by studying modifications to a CT-integrated lesson, Lesson 0, made in pursuit of equitable participation, we can glean insights about the ways in which teachers think about equity in the science classroom. When asked about their specific modifications, teachers provide key insights into how they approach curricular design for equitable participation. This can be a useful method for other researchers moving forward who wish to understand how teachers think about and design for equitable participation in the science classroom.

7 | LIMITATIONS

While narrowing our focus to four teachers allowed us to provide a more in-depth analysis of teacher sensemaking and design choices, there are also limitations associated with having a small sample size. Most notably, the small sample size limits the generalizability of this study. Our results should be interpreted within the unique context of this study. Furthermore, all four teachers are white and teach in the same Midwestern region. It is important to note that the ideas discussed in this article are by no means a complete representation of all ideas and understandings of equitable participation, but rather represent a unique collection of conceptualizations and design choices from four teachers across four co-design workshops focused on CT-integration and equitable participation. However, the aim of our work is to provide a useful framework for understanding the ways in which science teachers conceptualize and design for equitable participation in CT-integrated curricula. To that end, we hope our findings can provide direction for future study.

8 | FUTURE WORK

Although the workshops and lesson redesign were focused specifically on making changes to promote equitable participation, our study did not try to assess the efficacy of these modifications. For example, Jason made modifications to encourage student collaboration and discussion to support his focal, Black male students. However, we do not have evidence that demonstrates a clear connection between this modification and Jason's desired outcome. Future research should aim to understand not only the design modifications, but also how such modifications are enacted in the science classroom.

As fellow co-designers, researchers were also forced to grapple with the very same question that this study sought to understand in teachers: What is equitable participation? Would modifications to Lesson 0 actually achieve equitable participation in a CT and STEM integrated classroom? Despite being understood in the context of this study as changes to improve equitable participation in the CT-integrated classroom, it is possible these modifications might not achieve such a lofty goal. Future research should assess the quality of such modifications by studying their enactment with diverse students.

This is also significant considering that modifications to Lesson 0 tended to focus on accessibility, inclusion, and relevancy. Unless there is attention to a wider spectrum of equitable

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participation and equity, it is possible that teachers will continue to focus on accessibility, inclusion, and relevancy and not social justice. Future professional development can use the co-design approach from this article to understand teachers' existing equity conceptualizations and then identify where to go with future professional development. We hope future co-design experiences can explicitly address combatting existing power dynamics—such as structural sexism, racism, and anti-Blackness—so that teachers can expand their conceptualizations of and modifications to support equitable participation in the context of CT toward justice and liberation for all learners. Future constructionist co-design sessions and professional development may benefit from explicitly framing the support of equitable participation through the four tenets of culturally relevant education (CRE; Aronson & Laughter, 2016). The four CRE tenets are:

1. Developing connections between cultural references and academic skills and concepts.
2. Engaging students in critical reflection about their lives and the world around them.
3. Facilitating students' cultural competence.
4. Working to identify and dismantle oppressive systems through the critique of discourses of power (Aronson & Laughter, 2016; Spencer et al., 2021, p. 364).

It is important to build on teachers' existing conceptualizations and modifications related to equitable participation by supporting the integration of all CRE aspects. Future work will focus on integrating CT, STEM, and CRE to support synergistic, meaningful, and effective learning for all students.

ACKNOWLEDGMENTS

The authors appreciate the interest and participation of the teachers and students who made this work possible. This work was made possible through generous support from the National Science Foundation (grant Nos. CNS-1138461, CNS-1441041, DRL-1020101, DRL-1640201, and DRL-1842374) and the Spencer Foundation (Award #201600069).

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Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Levy, M., Peel, A., Zhao, L., LaGrassa, N., Horn, M. S., & Wilensky, U. (2025). Secondary science teachers' conceptualizations and modifications to support equitable participation in a co-designed computational thinking lesson. *Journal of Research in Science Teaching*, *62*(5), 1167–1201. https://doi.org/10.1002/tea.21998

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