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Teacher Candidates' Conceptions and Practices of Computational Thinking for Equity

RESEARCH

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ABSTRACT

This study documents novice science and math teachers' developing pedagogical approaches to integrating computational thinking (CT) and data into their courses to support educational equity and social justice. The 10 novice teacher candidates (TCs) studied were part of an urban teacher residency program that empowered them with an asset-based pedagogy we describe as "CT for Equity." Drawing on coursework and interviews as data, we asked three questions: What are teachers' conceptions of CT? What are their CT instructional practices? And how did their students respond to those practices? To explore conceptions of CT, we used Kafai et al.'s (2020) articulation of three frames of CT – cognitive, situated, and critical approaches – and found that the TCs' conceptions do not narrowly fit into one of the three frames, but rather they mix and match components of the perspectives to support a range of student outcomes, from transferable skills to preparing youth to explore social justice issues. We also identified a small but powerful set of core practices that the teachers used to support learning outcomes, including integrating data on locally and socially relevant issues. We present group-level trends and three classroom stories, or profiles of practice, to illustrate the generative ways TCs blended priorities from the three frames in instruction. The diversity in the TCs' conceptions and practices deepens understandings of asset-based pedagogies in CT by shining light on the rich and varied ways that math and science teachers meet the needs of their minoritized students.

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In science, technology, engineering, and mathematics (STEM) education, there is a rally around the topic of computational thinking (CT) and new questions on how to ensure equitable access to CT education (Grover & Pea, 2013; Pinkard et al., 2020). Computational thinking refers to a thought process involved in expressing solutions in a way that can be carried out by a computer (Lee, 2016) including systematic analysis, exploration, and testing of solutions to open-ended and often complex problems based on analytical processes rooted in the discipline of computer science (CS) (CSforCA, 2021). Importantly, CT is not decontextualized or instrumental skills, but rather is inherently personal and political (Kafai et al., 2020; Vee, 2017). Social inequities caused or exacerbated by computing and the lack of diversity in the practices and participation of computing and K-12 computing education must be scrutinized.

While CT is quickly becoming a prerequisite skill for most endeavors of the 21st century (Barr & Stephenson, 2011; Kafai & Proctor, 2022; Wing, 2008) there are at least two significant issues of educational equity that limit students' opportunities to learn the data sensemaking demanded of engaged citizens (Buitrago Flórez et al., 2017). First, there is a critical shortage of qualified teachers, particularly in high-needs schools serving minoritized students (Garcia et al., 2022; Koshy et al., 2021) Second, misleading data artifacts integrated in current computing maintain and perpetuate social inequalities (Bradford, 2017; Robinson, 2019), while issues of equity and social justice are largely absent from the CT/CS coursework of novice teachers. A disheartening finding from a recent survey shows that 39% of CS teachers do not see the importance of addressing the role of computing in perpetuating biases related to racism, sexism, and other social justice issues in the classroom (Koshy et al., 2021). With educators unprepared to address the intersection of social justice, data, and computing in their classroom, students will be unprepared to encounter these issues in their world (Jones & Donaldson, 2022; Ko et al., 2020; Philip et al., 2016; Santo et al., 2019; Yadav & Heath, 2022).

In this paper, we examine the participation of novice teacher candidates (TCs) in an urban teacher residency program that integrates CT practices as a contemporary approach to learning math and science that is relevant to the data-rich and technology-driven context of today's classrooms. Meaningful integration of CT opportunities into STEM curricula can deepen learning of math and science concepts (NRC, 2011; Sengupta et al., 2013). However, embedding CT in STEM education, as is the approach with the Science and Engineering Practices of the Next Generation Science Standards, is not enough to ensure that concepts and skills will reach students. To respond to the various challenges facing novice educators, the TCs studied here were empowered with pedagogical practices and purposes to integrate CT in their math and science classrooms as a strategy to support both disciplinary learning and addressing issues of social justice that matter to students. We call this approach "CT for Equity," a pedagogy to empower students to use CT to explore, express, critique and create artifacts about the world (Authors, 2023). CT for Equity offers an approach to integrating culturally responsive-sustaining computer science education in STEM courses to support educational equity and social justice for minoritized youth (Kapor Center, 2021; Santo et al., 2019; Vogel et al., 2017). To understand how TCs developed their own approach to CT for Equity we answer three questions in this paper: What are teachers' conceptions of CT? What are their CT instructional practices? And how did their students respond to those practices?

CT FOR EQUITY

STEM+C³ (with the three C's representing computer science, computational thinking and community of practice) is an urban teacher residency program housed in the UCLA teacher education program. The mission of both STEM+C³ and UCLA's teacher education program is to prepare teachers with the commitment, capacity, and resilience to work in the most underserved communities. The program aligns a humanizing teacher education program (Bartolome, 1994) with K-12 academic achievement standards and state and national content standards. TCs are matched with a mentor to begin their student teaching on the first day of school and follow a gradual release of responsibility model (Fisher & Frey, 2013). After one year of coursework and student teaching, TCs obtain their preliminary teaching credential in a science or math discipline, and secondary authorization in CS. During the second year, the TCs continue taking courses towards the completion of a master's in education degree. The TCs were supported in developing their own CT competencies through a series of four CS courses and were supported in developing pedagogical content knowledge for CT integration in methods and seminar courses (see Perez et al., 2023 for an extended program description).

STEM+C³ empowers TCs with an approach we describe as "CT for Equity." In this approach, CT is conceptualized as a set of seven practices, summarized in Figure 1. Briefly, below we describe the key components of the program (see Perez et al., 2023 for an extended program description). First, CT for Equity aims to help TCs integrate CT in the required math and science courses that they teach. The goal of engaging in CT through core disciplinary

Computational Thinking for Equity

CT for Equity seeks to empower students to use problem-solving and design skills that are informed by computing to explore, express, critique, and create artifacts about the world around them.

Relating course concepts to CT and data	Equity, classroom ecology, and discourse
Develop and Use Abstraction Consider and focus on key components and filter out unnecessary details to make problems easier to solve and includes acknowledging the benefits and consequence of generalizations and or lost details. **Decomposition** Break down a problem of interest into smaller, more manageable components, and the ability to describe this process in detail in order to make decisions, obtain help or find solutions. **Algorithmic Thinking** Recognize when a solution to a problem can be broken into step-by-step instructions. This set of instructions considers the audience, the purpose, and can be used by someone else or a computer. **Debugging and Evaluating** The ability to identify and correct errors within an algorithm, and ensuring your solution is effective, feasible, and considers the impacts on various identities.	**Exploring Equity Issues through Computational Thinking and Data** Encourage alternative ways of solving problems. Promote inclusivity and provide universal access to all students, particularly those from underserved and intersectional populations. **Collaborate Around Computing and Data** Work with others to understand, develop, and design computational artifacts or data visualizations to explore and explain phenomena, solve problems, or develop solutions that matter to students. **Communicating with and About Computing and Data** Describe, explain, and justify observations, patterns, and predictions around computational artifacts and data within the context of the problem as well as communicate applicable ethical considerations.

Figure 1 Dimensions of CT for Equity (modified from Perez et al., 2023).

areas is to increase student access and participation to CT and CS concepts and broaden both teacher and student perspectives around what CS can look and feel like (Weintrop et al., 2016). Second, CT for Equity closely ties CT to data-related tasks such as the data cycle and the statistical investigation cycle (Bargagliotti et al., 2020) with the goal of preparing students to "work with data and be critical consumers" (Gould, 2021, p. S16). Third, CT for Equity supports educators in creating a classroom environment and curricula that affirms students' rightful presence in the STEM classroom and larger STEM community (Barton & Tan, 2019). Teaching practices and pedagogies anchored in CT for Equity,

> support the integration of students' lived experience and culture as an asset that also provides [a] differentiation pathway for students. [PROGRAM] explicitly focuses on educational equity and justice, and provides pre-service teachers the opportunity to situate relevant social justice topics into curriculum, and use CT practices to open opportunities to explore issues of social justice within the classroom. (Perez et al., 2023, pp. 3)

Moving beyond concepts and practices, CT for Equity empowers teachers and students to use their CT and data skills to develop and critique narratives about the world around them emphasizing the context, ethics, and implications embedded in data. In STEM+C^3, CT, data, and equity are inextricably linked, and this nexus serves as the coherent thread that weaves together different facets of the program.

THEORETICAL AND CONCEPTUAL FRAMEWORKS

We view the learning of TCs as a historically and culturally informed process of interpreting and implementing the theories and pedagogies emphasized in their university coursework (Jurow et al., 2012). As such, in this study we use the concept of Situated Sensemaking (Rosebery & Puttick, 1998) to trace TCs' experiences as they engaged with theories and pedagogies of CT and enacted and revised their practices.

Conceptually, our design and analysis are anchored in the frameworks of asset-based pedagogies (Gay, 2000, 2013; Ladson-Billings, 1995, 2014, 2021; Mensah, 2011; Paris, 2012) and the dialogue of theories about CT education advanced by Kafai, Proctor and Lui (2020). We will explain each briefly below, and then explain the intersection in CT for Equity. First, asset-based pedagogies center students' identities, cultural background, and lived experiences in learning with the aim of supporting minoritized students in academic achievement, as well as developing cultural competence and critical consciousness – the three tenets of culturally relevant pedagogy (Ladson-Billings, 1995). These goals guided the design of CT for Equity as the broad student outcomes we hoped teachers would support.

Kafai et al.'s (2020) framework of three approaches to CT education helped us design for and study CT teaching and learning. The framework presents three perspectives or approaches within CT education – cognitive, situated, and critical frames – as partial and contingent in guiding the interpretation and understanding of instructional activities. The dominant frame in CS education is cognitive, which emphasizes skill building and competencies to help students understand key computational concepts for future careers. In this approach, CT learning happens through instructional activities that introduce students to computing concepts to promote individual problem solving and comprehension of CS concepts (Grover & Pea, 2013). The situated framing of CT emphasizes interest-driven and peer-supported activities so students can design meaningful, shareable digital artifacts. In this approach, CT supports personal expression and interpersonal connections with authentic contexts to emphasize that computing can engage diverse, historically excluded students to use computing as a personalized tool for self-expression (Burke & Kafai, 2012). The critical framing has emerged most recently which emphasizes the examination of, and resistance to, oppressive power structures and digital media content. To help youth confront oppressive forces, this approach to CT engages students with the political, moral, and ethical challenges of their world to develop a sense of agency and critical awareness of the underlying infrastructure that support injustices and inequities in everyday computation (Vakil, 2014; Vakil & Higgs, 2019).

CT for Equity, as a set of pedagogical practices that TCs in STEM+C^3 learned to enact, is primarily anchored in the situated and critical frames of CT (Kafai et al., 2020) to support pedagogies that are culturally relevant (Ladson-Billings, 1995; 2014), culturally responsive (Gay, 2000) and culturally sustaining (Paris, 2012). Specifically, CT for Equity is based on the conjecture that situated and critical frames of CT will support students' academic achievement and sociopolitical consciousness. This third tenet of culturally relevant pedagogy – developing sociopolitical consciousness – is under-studied and under-utilized, particular in the context of STEM education (Jones & Donaldson, 2022; Madkins & McKinney de Royston, 2019). Ladson Billings (1995) described that students' sociopolitical consciousness "allows them to critique the cultural norms, values, mores and institutions that produce and maintain social inequities" (p. 162) which requires that students and teachers explore issues of power in their discipline. This work demands addressing issues of oppression in STEM learning spaces (Laughter & Adams, 2012). Teachers empowered with CT for Equity pedagogy learn to use and teach CT to address oppression embedded in computing and data alongside their students. This is the primary mechanism by which we hypothesize teacher practices based in CT for Equity will support educational equity and social justice. In answering our research questions around TCs' conceptions and practices of CT, as well as their students' responses to these practices, we document classroom examples of the rich and varied ways that math and science teachers use CT and data to meet the needs of their minoritized students as they work towards equity and justice.

METHODS

CONTEXT AND POSITIONALITY

Data for this study were collected during the 2020-2021 school year while learning and instruction were remote due to the COVID-19 pandemic. TCs worked in a large urban school district and Title 1 schools serving low-income students of color in Los Angeles County. The logistics and dynamics of remote learning resulted in less K-12 instructional time than a typical school year and different forms of engagement both in the high school and university classroom settings. Relational dynamics, interactions, and data collection were constrained in many ways with observations of TCs solely being video recorded rather than in-person. The TCs did not meet their students face to face, many youths preferred to participate with cameras off, and the research and residency program teams did not interact with the high school students at all.

The first cohort in STEM+C^3 included 7 science and 3 math TCs. Demographically, this group was comprised of 7 female-identifying and 3 male-identifying candidates, including 3 Latinx, 3 White, 2 Asian American, 1 African American, and 1 Middle Eastern American candidate. The TCs were all STEM majors in college but only 3 had training in computer science, specifically in programming. While characterizing TCs' initial and evolving views on equity is out of the scope of this paper, it is important to highlight that the TCs' participation in STEM+C^3 and UCLA's teacher education program was based on the social justice agenda they aspired to pursue as educators.

The authors were part of the STEM+C[3] design and implementation, and we all have backgrounds as science educators and field supervisors. Author1 is a White woman from the metropolitan area of UCLA, Author2 is a Black woman from a large East coast city, and Author 3 is first-generation Mexican American woman from the metropolitan area of UCLA, and the director of the STEM+C[3] program. Individually and collectively, our work is grounded in critical pedagogies and practices to support youth and educators in developing a sense that STEM learning can be meaningful and joyful, as well as critical consciousness to address oppressive forces in education and the world. When answering Vossoughi and Vakil's (2018) question of "towards what ends" teachers will integrate of CT into STEM classrooms, our organizing commitment is to epistemic justice that affirms the dignity of all learners and to open opportunities to use STEM concepts and practices to explore and address issues of social justice.

DATA SOURCES

We collected and analyzed four specific artifacts that were part of the TCs' coursework to understand their conceptions, practices, and student responses, each of which we briefly describe below along with the analytical function. First, we collected end-of-quarter reflections that asked about their objectives, challenges, and successes in CT integration. These included specific questions on how the TCs defined CT, a summary of what CT-related activities they had facilitated with their students that quarter, how their students engaged in those activities, and how they saw CT integration advancing their goals of education equity and social justice. These reflections were short segments spoke primary to our research questions on conceptions and practices. Second, we collected a project-based learning lesson plan (Kingston, 2018; Larmer et al., 2015) that outlined student roles, driving questions, tasks, and assessments. While these were meant to be disciplinary lessons focused on science or math concepts, the TCs were required to include a "CT moment" as part of the lesson in which they helped their students use CT to learn a disciplinary concept. These lesson plans primarily provided data on teaching practices. Third and fourth, the final project for TCs' first CS course, that asked TCs to describe their thinking and learning on CT, and the final project for their second CS course, that asked TCs about the value of CT to students, how their positionality informed their CT instruction, success and tensions in teaching CTs, and learning goals moving forward, were collected. These were the most extensive samples of writing collected and spoke broadly to all three research questions.

We also analyzed semi-structured interviews conducted at the end of the first school year. The interview protocol included the question, "How would you describe how CT is showing up in your thinking and teaching?" TCs' responses to this open-ended question spoke to all three research questions. In the absence of observations and student-level artifacts (unavailable because of pandemic restrictions), we used these data to measure conceptions and to approximate practices and student responses. We obtained Institutional Review Board permission from the university and informed consent from participants to ethically conduct this research.

ANALYTICAL APPROACH

Analysis of data took a deductive approach for all sources. To code TCs' conceptions of CT, we transformed Kafai et al.'s (2020) framework into a nested coding scheme with the three frames as high-level nodes (cognitive, situated, and critical frames) and the three perspectives as categories within each node (unit of analysis, epistemology, and prioritized learning outcomes). In analyzing the data, we used these nodes and categories for structural coding (Saldaña, 2014) to index the TCs' writing. Then we coded excerpts of the TCs' writing with the learning perspectives associated with the various categories and frames. These codes are presented in Table 1. In addition to this deductive approach to coding, concepts emerged during analysis that were not included in Kafai et al.'s framework which necessitated a more inductive approach. For these emergent concepts, we developed an inductive code (labeled with an asterisk in Table 1 and described in the findings section).

To code TCs' practices for CT integration and students' response, we developed an approach that combines the CT for Equity practices (Figure 1) with an observational protocol to create a coding scheme. Specifically, we analyzed TCs' reflections on their own pedagogical practices, or teacher actions, and their students' responses to those practices, or student actions, within five dimensions of CT. Table 2 operationalizes observable teacher and student actions promoted in CT for Equity that we identified in their written reflections. For coding, we read the TCs work to identify the actions they described themselves taking (teacher action codes) and the actions they observed their students taking (student actions) to deductively code data. Student action codes were only ascribed to actions TCs observed, not aspirational or future outcomes. We acknowledge that classroom observations are the ideal site to identify teacher and student actions, and therefore our count of actions is certainly an underestimate because teachers did and saw more than what they reflected on in coursework.

To support reliability, all authors initially coded the same subset of data using the coding schemes described in Tables 1 and 2. We discussed areas of agreement and disagreement, and refined codebook definitions until a consensus was reached. Heather and Symone completed this process twice more using another subset of data until a consensus on all codes for a single dataset was reached and all codebook definitions were refined. The remaining data were subsequently coded by Authors 1 and 2 individually based on the consensually developed definitions (McDonald et al., 2019).

	COGNITIVE FRAME	SITUATED FRAME	CRITICAL FRAME
Unit of analysis category	Individual learner (7)	Activity system of classroom or school (5)	Existing structures of power in society (2)
Epistemology category	Skills, competencies, proficiencies (7) Knowledge of a particular discipline (5)	Practices (7) Participation in CS/CT (0) Preparation for future learning (7)	Awareness of ideologies or social inequalities (1) Strategies for social action (1)
Learning outcomes category	Measurable transferable skills in computational concepts and practices (7) Economic or employment opportunities (2)	Equity (4) Identity development (1) Interest (4) Creativity and creating personally meaningful applications (1) Supporting social interactions and building community (2) Metacognitive thought process for problem solving * (9)	Critical understanding of power and privilege in education or social contexts (5) Understand/critique existing computational infrastructures (4) Enact social change for justice (4) Create apps to promote thriving, awareness, and activism (0)

Table 1 Coding scheme and findings for CT conceptions organized by Kafai et. al.'s (2020) frames and categories.

Notes: * Emergent code not included in Kafai et al.'s (2020) framework; n = number of teacher candidates that espoused each perspective

CT DIMENSION	TEACHER ACTION CODES	STUDENT ACTION CODES
Exploring social justice issues through CT and data	Framing learning as tied to real world phenomena or to students' identity/community (7) Recognizing how society and computing interact to create/limit opportunities (0) Acknowledging misrepresentation of groups in computing (2)	Reflect on lessons learned from mistakes (0) Develop a fail-forward mentality (0) Engage in critique of bias in data or computing (1)
Collaborating around CT and data	Positioning computational artifacts as practical tools (1) Positioning computational artifacts as tools for societal problems (2) Positioning computational artifacts as tools for personal expression, as open to bias (1)	Persistence to work through difficult problems (0)
Communication around CT and data	Highlighting and labeling CT practices used in tasks (1) Reflective conversations about strengths/limitations of technology and data being used (1)	Engage in dialogue that identifies and incorporates CT practices (data talks and data cycle) (3) Elaborate understanding of instructional goal through data storytelling (3)
Relating course concepts to CT and data	Relating course concepts to CT practices (abstraction, decomposition, algorithmic thinking, debugging, modeling) (10) Relating course concepts to data including primary, second, socially relevant and messy data (9) Engaging in the data cycle or data visualization (1) Situating data as necessary to make/evaluate claims (1)	Connect course concepts to CT practices (abstraction, decomposition, algorithmic thinking, debugging, modeling) (3) Integrate data in disciplinary work and recognize when data is (1) Ask statistical questions (0) Interrogate data to consider complexity, bias, and errors (3)

Table 2 Coding scheme and findings for CT practices) organized by CT dimension and teacher or student actions.

Note: n = number of teacher candidates that shared each action.

FINDINGS

We organize our findings around three "profiles of practice," or stories that the TCs told about their classrooms, to illustrate examples of the case of TCs' blended and generative conceptions and practices. These classroom stories describe how the TCs engaged students in using CT and data to investigate three pressing social issues: food deserts, climate change, and representations of diversity in the media. These profiles of practice were selected because they represent instructional activities that the TCs collaboratively designed in their teacher education courses and are representative of the instructional goals of STEM+C^3 and CT for Equity. We highlight one teacher in each profile who was selected because they wrote about the instructional activities in the greatest detail. Following analysis of the three profiles, we present group-level trends and additional excerpts to elaborate on variations of conceptions and practice.

To answer our first research question on how the TCs' conceptualized CT, Table 1 quantifies group-level trends identified. The number next to each code represents the number of TCs (out of 10) who espoused each perspective on CT. The findings illustrate that all 10 TCs held conceptions of CT aligned with the cognitive and situated frames, while 8 also conceptualized CT aligned with the critical frame. To answer our research questions on teacher practice and student response, Table 2 quantifies group-level trends. We found a small but powerful set of core practices the TCs enacted in their classrooms along with their students' responses to those practices. The three teacher actions that were taken universally or almost universally in the cohort were framing learning as tied to real-world or community-oriented phenomena, relating course concepts to CT practices, and relating course concepts to data.

FOOD DESERT PROFILE OF PRACTICE

The first profile of practice describes the implementation of an instructional unit oriented to food justice and data on food deserts. This unit was collaboratively developed by a team of 3 TCs teaching high school chemistry or biology, and here we highlight the story told by TC2, a female science teacher. TC2 tied the classroom tasks and science concepts to the real-world, locally relevant, and equity-oriented phenomenon of a lack of healthy food and grocery stories in the students' neighborhood and other urban areas. This profile of practice highlights TCs' thinking about and instruction for empowering students to use CT and data to explore and critique issues of inequity in their local community.

TC2 taught a set of lessons on food chemistry and food justice with the instructional goal of students determining whether low-income communities in Los Angeles were more likely to be impacted by food insecurity. She taught the scientific concepts of chemical change that take place during cooking and baking as situated in the sociopolitical context of food deserts. To do this, TC2 provided secondary data sets on local grocery store distribution and tasked students with collecting their own primary data on food accessibility in their neighborhood. She observed her students engaging in a range of CT practices, most commonly noting how student used CT practices to understand chemistry concepts. For example, students engaged in abstraction by identifying the salient features of the system of inquiry. TC2 described the unit by writing,

> We looked at data focused on Los Angeles and worked to investigate who has access and who might not have access to food based on the analysis and interpretation of the data. During this lesson I also had students collect data about the accessibility of food in their own communities and assess whether their community might be considered a food desert and then we talked about ways to combat these issues. Students used pattern recognition to discover that low-income communities were most impacted by food insecurity and on average had more liquor and convenience stores than actual grocery stores or farmers markets.
> *TC2*

Her students also connected course concepts to the CT practices of modeling and simulation to evaluate outcomes of modeled chemical reactions with products and reactants relevant to cooking and meaningful to nutrition.

Pedagogically, in this unit TC2 used the practice of situating data as necessary to support three learning outcomes. First, she prioritized the critical learning outcome of helping students understand power and privilege embedded in the social systems of food access. Second, she expressed the situated learning outcome of developing students' interest in STEM and CT when describing the importance of using local data because "students are able to connect more closely with issues in their neighborhood." Finally, she expressed her commitment to the cognitive learning outcome of learning disciplinary practices when she noted that she hoped students would "engage more deeply with scientific investigation."

Within each of these prioritized learning outcomes, TC2 targeted her teaching to both the cognitive scale of the individual student and the situated scale of the classroom activity system. In explaining changes at the scale of the individual, she wrote,

> Our students need to learn how to use their computational thinking skills to work through analyzing and interpreting the data presented to them. There is a lot of falsified and skewed information that is presented daily and our students need to be able to distinguish between what is real and what is fake. *TC2*

In explaining changes at the system level, specifically around classroom norms, she wrote,

> Within our society it may be challenging to think critically because throughout schooling we are usually taught that there are wrong and right answers. This ideology especially holds within STEM courses without acknowledging that many STEM advances and discoveries have been developed through failure. *TC2*

In working simultaneously towards multiple outcomes at multiple scales, TC2 hoped her students would build a "problem solving skillset that integrates critical thinking." As a model unit of CT integration, this food justice unit may support educational equity through the high levels of engagement and may support students in developing sociopolitical consciousness about the critical dimensions of food systems.

CLIMATE CHANGE PROFILE OF PRACTICE

The second profile of practice describes the implementation of an instructional unit oriented to data on climate change and environmental justice. This unit was collaboratively developed by 3 TCs teaching high school chemistry or biology which also included TC2; we draw on her data again to tell the story of these learning activities. Representative of the common teacher action of framing learning around real-world issues, this unit tied students' work of learning CT and using data to their everyday experiences with extreme summer heat.

In learning activities exploring climate change and access to greenspace, TC2 had students analyze and interpret data to support their work of designing and modeling parks that would address inequities in urban greenspace and related socioecological injustices in the neighborhood. Paired with instruction on standard-aligned concepts of the carbon cycle, the greenhouse effect, and how human activities unbalance these climate systems at the global scale, the TCs also facilitated place-based investigation and locally relevant problem-solving. TC2 had students collect primary data by interviewing family and friends on park quality and resources in the community, and what they believed was missing in their park spaces. She noted that by having students involve family in the data collection process, students collected social justice-oriented data that "amplif[ied] their voices and their family/community voices through including the interviews as evidence." In gathering primary data, TC2 observed students interrogating data to consider complexity, bias, and errors. Students' role as data collector and analyst engaged them in collaborating around data and supported their learning about the canonical chemistry concepts of the climate system such as electromagnetic radiation and albedo effect.

TC2's epistemological stance for her climate change unit was anchored in the situated frame of CT as a set of practices and a thought process. This conceptualization of CT informed how she positioned students to use CT and data in classroom activities. She stated,

> The parks data used CT by identifying the problem 'Why are parks not evenly distributed?' By identifying this question, [students] were able to use decomposition to help breakdown the question into more simple parts. When you are able to break down the question, then it is easier to understand and answer the question. *TC2*

TC2's pedagogical strategy in the climate change unit aimed to support two learning outcomes. First, from the situated frame, she hoped students would engage in social interactions that build communities that strengthen minoritized voices through the inclusion of their family in scientific inquiry. Second, from the critical frame, she hoped students would develop critical awareness, specifically using CT to understand how communities are impacted by the lack of parks and greenspace. To explain these goals, she wrote,

> The purpose of this project is to get students to think about how climate impacts different communities and how we can fight against heat and climate change. Since we all live in Southern California we are aware the city gets a lot hotter than other areas and through investigation we will work to understand why this happens. Many of my students are concerned about their neighborhoods and how they are impacted. This project connects to families because they will be involved in the data collection process through interviews and students will work to amplify their voices and their family/community

> voices through including these interviews as evidence in their proposal. *TC2*

Overall, TC2 hoped that through this unit students would use their knowledge of CT and chemistry to explain access to parks as embedded in systems of privilege, and to empower students to feel capable of creating change in their communities to address climate change.

MEDIA REPRESENTATION OF DIVERSITY PROFILE OF PRACTICE

The third profile of practice describes the implementation of an instructional unit oriented to diversity and (mis) representation in the media, specifically in videogame characters. This unit was collaboratively developed by a team of 3 math TCs, and here we highlight the story told by TC1. This profile of practice highlights TCs' thinking about and instruction for empowering students to use CT and data to create artifacts that re-imagine the world around them.

Through the pedagogical practices of tying learning to real-world phenomena and relating concepts to data, TC1 enacted a unit where students learned math and CT practices and concepts through analyzing the lack of diversity and misrepresentation of marginalized communities in videogames.[1] They provided students with secondary data on the demographics of videogame characters, and had students collect primary data on the characters in the videogames they played. They noted that analyzing data from their own videogames was significant as it provided "students real-world contexts to develop their CT skills." Specifically, the CT skills that TC1 observed students engaging in were data talks and considering bias in data sets.

In this instructional unit, TC1 aimed to support learning outcomes from all three frames of CT. First, TC1 used CT and data practices to support the cognitive outcome of building transferable skills. They wrote,

> CT allows [students] to develop stronger critical thinking skills that can be used throughout their lives…CT can provide students with the data literacy skills needed to read, understand, create and communicate data as information…[It] is critical for students to have a future where they can decipher and criticize what is provided [to] them. *TC1*

Second, TC1 worked towards the situated outcome of helping students develop a thought process and mindset for problem solving. They believed that by having students practice CT and data skills to investigate diversity in videogames, they could help students further develop the skills to use CT and data practices to "tackle problems in the future." TC1 credits CT and data practices with helping students "turn complex dilemmas…into less intimidating and more manageable sub-problems that can be easier to find solutions to." This mindset, they noted, helped students to "think about the thinking process and whether or not there is a more efficient way to solve the problems they come across." Third, TC1 aspired to the critical learning outcome of students understanding and critiquing existing computational structures. They wrote that,

> Students are living in a world where they are constantly bombarded with information…as a result, they must have the tools needed to be able to critically analyze the information they are receiving in order to determine if it is accurate and credible…[CT can help them to] challenge computational artifacts and systems of power. *TC1*

The three learning outcomes that TC1 aimed for in this videogame misrepresentation unit – CT skills, a problem-solving thought process, and critiquing computational structures – are all inherently connected. TC1 did not separate these outcomes as they designed and enacted pedagogical practices but came to see cognitive skills as supporting a problem-solving mindset that could be used beyond the classroom to understand issues that matter to students' lives.

GROUP-LEVEL TRENDS

The three profiles of practice tell detailed classroom stories on TC1 and TC2's conceptions of and instruction for CT for Equity. We now situate those stories in findings across the cohort – as quantified in Tables 1 and 2 – by presenting additional excerpts and analysis to describe both the representative nature of the themes in the profiles as well as variations in the TCs' thinking and teaching. We start by discussing group-level trends in conceptualizations of CT aligned with the cognitive and situated frames. Then we describe the prioritized learning outcomes from all three frames, and last, we explore variation in teacher actions.

Cognitive and situated perspectives on scale and epistemological commitments

For the first two categories of CT conceptualizations, unit of analysis and epistemological commitments, the TCs' views are almost entirely aligned with the cognitive and situated frames. TCs described the unit of analysis, or the scale at which they targeted their pedagogical practices, as the individual learner and the activity system of the classroom. In addition to the excerpts from TC2 in the food justice profile, TC5 described targeting the individual learning, as aligned with the cognitive frame, when she wrote, "Developing [CT] skills will support [students] greatly in college, and it will also give them the ability to analyze and decide if they agree with the arguments of others based on the data they present." This statement explains how TC5 imagined CT integration can impact students individually. TC3 and TC8 described targeting the activity system of the classroom or school community:

> In a science class, or any class for that matter, this is also important for students to realize that learning is a continuous process which will involve making mistakes and finding out what went wrong. We have mostly been taught in school that if you get something wrong the first time, it's too late to fix it and we just have to take it as a loss. Computational thinking in class can look like allowing students to debug and evaluate their thinking by returning to the way they broke down the original problem or how they went about solving it. *TC3*

> Inquiry-based learning certainly intersects with computational thinking in many ways as students are given more freedom to pick apart complex problems and develop their own solutions to them. Computational thinking in a classroom moves away from teacher lecturing and being the sole source of knowledge and empowers students to come up with their own ways to solve problems. *TC8*

In describing the activity system of schools and classrooms as their target, these TCs identified norms of schooling that they view as problematic for learning and educational equity and described how their CT instruction might disrupt these schooling practices.

These examples show the ways in which the cognitive and situated frames of CT simultaneously animated TCs' thinking. This situated perspective on CT, which emphasizes interpersonal connections with authentic contexts and engaging historically excluded students, was explicitly designed for in the CT for Equity framework. We ascribe these findings to TCs' understanding of CT for Equity as working to promote inclusivity, particularly for those from underserved populations. The cognitive frame was not explicitly designed for in the CT for Equity framework, but its pervasiveness in the TCs' past and ongoing education spaces likely influenced their adoption of and alignment with this frame. These findings show that adopting a conceptualization of cognitive frames of CT did not limit the TCs from also developing situated perspectives on learning.

Situated commitments and goals of CT for future problem solving

From the situated frame, we commonly identified the perspective that CT could prepare students for future learning (epistemology category) and the emergent theme of students developing a productive metacognitive mindset for problem solving (outcomes category). Seven TCs described learning CT as preparation for learning outside of the classroom and how this mindset could provide a broad and flexible framework for real-world problem solving. For example, TC3 and TC6 described this understanding of CT when they wrote,

> CT is not simply trying to think about information as cold facts or a process of thinking like a computer, but rather an ongoing and ever-changing thought process that is constantly being revisited and reevaluated. *TC3*

> The principles of CT give [students] a simple, broadly applicable framework to guide them as they try to solve these real-world problems. The CT framework does not actually tell them how to solve a problem, but provides an opportunity for metacognition. *TC6*

Often connected to this epistemological understanding were TCs' goals for how students would use CT in the future. The most identified prioritized learning outcome is the emergent theme that CT integration will help students to develop a productive, transferable approach to problem solving and thinking that includes metacognitive reflection. Here are two examples of TCs describing this goal:

> I think centering learning around problem solving and investigating questions is the primary way I would like to incorporate CT and the data cycle into my classroom. By centering learning around problem solving and investigation, I believe we can support and encourage students to persevere in their learning, and also the understanding that there are situations where there is no "right" answer as long as they can support it well with their evidence. *TC5*

> I will talk to my students about debugging when we perform laboratory experiments and things don't go as expected. This is such a great learning experience and "teachable moment", especially as I hope to plan labs that are exploratory and student-driven rather than cookbook experiments. When something "goes wrong" during the course of a laboratory experiment, we can use the strategies

> involved in debugging to trace back our steps and figure out what might have gone wrong and how we can adjust our procedure to account for it. *TC8*

These examples illustrate the finding that TCs hoped CT learning experiences would help students develop a positive attitude about failure as they troubleshoot problem solving. These situated perspectives on CT embody the CT for Equity framework insomuch as they support youth historically excluded from computing in developing connections to and within the discipline that they can use productively in a wide range of present and future contexts.

Prioritized learning outcomes across three frames of CT

The third category analyzed and quantified in Table 1 was prioritized learning outcomes. We identified almost equal instances of the TCs aspired outcomes across the cognitive, situated, and critical frames. Here we present additional examples aligned with the critical frame to show variations that expand the goals identified in the profiles of practice. TCs expressed the goal of helping students use CT to understand the role of power and privilege in social contexts, educational contexts, or artifacts that are meaningful in their lives. Below TC4 and TC10 articulated this goal:

> Students [are] citizens of a digital world where technology is becoming a new tool for some more covert forms of oppression. There is so much misinformation and misrepresentations of data out there that students need to be able to navigate. If students understand the process behind the production of this information or misrepresentations of data, then students will have an easier time understanding the information. *TC4*

> Thinking critically and logically is something that can benefit students not only in other subjects, like math and science, but also in their everyday lives as they readily consume digital and visual media. With improved computational thinking skills, particularly in decomposition and pattern recognition, students can digest all media they consume through a more critical lens. In the age of fake news and viral social media, it can be very easy to believe everything presented to us at face value. *TC10*

Integrating CT with the goal of helping students critically understand systemic inequalities and injustices through their sensemaking about data represents a transformative learning outcome. Engaging students with the political, moral, and ethical challenges of their world, and using CT and data practices to confront oppressive forces is a major departure in the status quo of computing education that CT for Equity promotes.

Teacher practices for CT integration

The three teacher practices most identified – connecting concepts to data and CT and connecting tasks to real-world phenomena – are all interwoven in TCs' actions. The TCs framed debugging, decomposition, and generalization as practices for understanding and critiquing local and socially relevant data. In this section, we describe the range of phenomena and data sets TCs anchored instruction in.

A physics TC framed instruction on momentum around earthquake preparedness, a topic relevant to Southern California. A chemistry TC facilitated students collecting virtual measurements of atomic radii with the goal that they would "form their own ideas about the horizontal and vertical trends" of the periodic table. A biology TC framed instruction on the immune system around the COVID-19 pandemic, including infection and vaccination rates. In describing these instructional activities as part of his PBL lessons, they wrote,

> Students will look at map data of areas most heavily affected by COVID-19 and compare it to map data of areas that have received the COVID-19 vaccine. Students will look at the socioeconomic disparities in various communities and figure out how to reach out to and engage these communities. *TC3*

This example of anchoring instruction in viral infections to teach concepts of immunity also illustrates the use of pandemic inequality data which is another example of a social justice relevant data set that TCs drew on. For another example of local dataset, a team of biology TCs framed a unit around data on local biodiversity, which TC7 and TC10 explained by writing:

> The mountain lion lesson is a great example of how you can breathe life into data- by teaching them about science in their surroundings. Science always seems so far away, something that happens in the Galapagos and in antiseptic labs, but it's happening here. Any time I can teach about data that relates to my students' community or interests I am excited by that. *TC7*

> Be it through the analysis of someone's calorie consumption and expenditure and predicting where their health will be in a year, through the evaluation of an ecosystem and the energy stored within it to find out what species are considered keystones,

> or even in the construction of solutions to LA's Mountain Lion problem. *TC10*

For primary data, looking at the same climate change unit described in the second profile of practice, TC8 "commissioned" students to be data collectors. They wrote:

> I commissioned my students to be data collectors for the local parks in their own communities by visiting the park, writing down observations, and also interviewing 3 other community members to hear their thoughts on how the parks can be improved. This data collection wasn't pointless because they then used this data to write a proposal to the Department of Community Services about how they believe their local parks should be improved. *TC8*

By visiting a park near their home and interviewing loved ones about local parks, TC8's students generated primary data as evidence for a persuasive letter advocating for more greenspace to reduce extreme heat.

TCs' rich and varied practices reflect that exploring data as a function of the demographics of a community, such as race, ethnicity and socioeconomic, was a central practice. Anchoring instruction in issues that explicitly explored social injustice helped TCs communicate that learning science, math, and CT concepts was connected to these issues. Framing STEM and CT concepts as tied to real-world, relevant contexts allow students to explore issues that matter to their identities, interests, and communities.

DISCUSSION

This study characterizes the way 10 novice teachers came to understand what CT is, how to incorporate CT into their STEM pedagogy, and what CT can help their students accomplish. Understanding that justice-centered computing education requires that we "deeply engage with the complexities of how computing intersects with systems of oppression" (Ryoo et al., 2022, p. 2), this study documents the work of novice teachers confronting those complexities in their teacher education program and with their students. The TCs in our case study blended and combined epistemologies and prioritized learning outcomes from the cognitive, situated, and critical frames of CT. We build on the conclusion of Sfard (1998) and Kafai and colleagues (2020) that while researchers label, silo, and segregate theoretical perspectives of CT, teachers in practice do not. The TCs studied here worked within and across all three metaphors of CT education: towards "acquisition" of CT skills for the individual student, towards "participation" in negotiating membership and social interactions of computing, and towards "action" of interrogating what is learned and how it is learned to challenge injustices (Kafai et al., 2020; Sfard, 1998). Findings from this study show that adopting a conceptualization of cognitive epistemologies and learning outcomes of CT did not limit the TCs' development of critical pedagogies. The TCs generatively blended across frames to support the diverse and expansive aspirations they had for their students' learning.

IMPLICATIONS, RECOMMENDATIONS, AND CONCLUSIONS

This study has implications for teacher education on how the values of asset-based CT pedagogies can translate to practice to support equity and justice. To contextualize how the diverse, concrete examples of practice documented in this study have implications for teachers learning to appropriate, enact, and bring to life asset-based computing pedagogies, we explore how the TCs work embodies many of the core values of the Kapor Center's culturally responsive-sustaining computer science education framework (Kapor Center, 2021). Specifically, we conjecture that the TCs learning about CT integration has the potential to support the academic achievement and sociopolitical consciousness on minoritized students.

First, to support academic achievement, TCs created a classroom culture that was inclusive and equitable where student voice, agency, and self-determination were prioritized, and family and community cultural assets were incorporated. We see these components come together in the activities where TCs' students interviewed family members and generated original data on everyday experiences thereby taking responsibility for their education and drawing on their diverse identities and experiences. When novice teachers are empowered to facilitate their students' work in making meaningful connections to concepts, making their thinking public, and feeling like their ideas are valued, they are able see how that work can support engagement and achievement for minoritized youth (Birmingham et al., 2017; NASEM, 2018). Second, to support the development of sociopolitical consciousness, the TCs enacted anti-racist practices and acknowledged racism in computing and data practices while encouraging sociopolitical critiques. We see these components come together across the epistemologies and prioritized learning outcomes for the critical frame of CT that was adopted by eight of the TCs in this cohort. Teacher education programs that attend to and mitigate racialized power dynamics embedded in classrooms and disciplines can help novice educators expand minoritized students' opportunities to engage in robust STEM learning, find connections between themselves and the discipline, and develop critical awareness of those power dynamics (Bang et al., 2017; Hand et al., 2012; Nasir et al., 2014; Tolbert et al., 2018). The examples of this case of novice teacher practice illustrate what is possible for teacher learning that values computing education as a strategy to support STEM disciplinary learning and address issues of social justice.

We recommend that programs supporting pre-service and in-service teachers in integrating CT in the classroom scrutinize the social inequities embedded in computing and data as an opportunity to learn disciplinary concepts, develop CT practices, and address issues of social justice. In these efforts, carefully navigating tensions with school district partners around positioning CT as an "add on" versus a core approach to leveraging critical thinking is necessary. It is advisable for teacher education programs and school-based instructional leaders to seek mutuality so novice and mentor teachers have opportunities to authentical integrate asset-based CT/CS pedagogies.

We do not claim that the pedagogies documented in this study represent finalized or idealized practices. Our findings and recommendations must be interpreted considering the limitation of this study, specifically that we drew on TCs' self-reflection of their conceptualizations and pedagogies rather than direct observations due to pandemic biosafety protocols. Understanding the outcomes and experiences of high school students more fully demands that we hear from them directly; data produced by students would allow us to move beyond their teachers' assessment of how they responded to CT for Equity, and instead explore how they engaged, learned, and developed in these contexts. Future work will be grounded in classroom observations of TCs' practice and artifacts of students' classroom work.

The conceptualizations and pedagogical practices of the novice teachers in STEM+C^3 illustrate the generative, productive, and potentially transformative outcomes of the CT for Equity framework. We have shown the ways in which 10 TCs' answered the question of "CS for what?" (Santo et al., 2019) by drawing across values and impact areas of CS visions of equity and social justice, competencies and literacies, citizenship and civic engagement, and school reform (Vogel et al., 2017). Equity, social justice issues, and connections to minoritized students' lives are too often absent from STEM and CT/CS teacher education programs and coursework (Mills & Ballantyne, 2016; Ryoo et al., 2021). This group of TCs show what is possible when we teacher education programs entrust teachers – and their diverse students – to become data storytellers in understanding, critiquing, and re-imagining the world around them.

NOTE

1 Gender nuetral pronouns are used here and occassionally throughout this section to further anonymize data.

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The authors have no competing interests to declare.

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