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EMPIRICAL STUDIES

"These two worlds are antithetical": epistemic tensions in integrating computational thinking in K12 humanities and arts

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ABSTRACT

Background: While advocates for integrating Computational Thinking (CT) into existing K12 classrooms have acknowledged and aimed to address various barriers to implementation, we contend that a more foundational issue – tensions between the epistemology of computing and those of existing disciplines – has largely been overlooked. Studies of contact between heterogeneous disciplinary perspectives in both pedagogical and real world professional settings point to other risks, and harms, that educators may need to consider as they attempt to integrate CT into their teaching. As such, designing for integrated CT pedagogies does not simply require addressing functional problems such as teacher professional learning and limited classroom time, but rather implicates complex epistemological navigations.
Objective: This manuscript explores epistemic tensions between Computational Thinking (CT) and K12 humanities and arts disciplines and possibilities for their resolution.
Method: Based on a Delphi study with 43 experts from three disciplines – language arts, social studies, and arts – as they engaged in 20 hours of focus group conversations exploring potential approaches to integrating CT these disciplines, analysis focused on identifying perceived epistemic tensions that can arise in the context of instruction and directions for their resolution.
Findings: We found 5 epistemic tensions that are explored in detail: contextual reductionism, procedural reductionism, epistemic chauvinism, threats to epistemic identities, and epistemic convergence, as well as a number of potential directions for navigating them.
Implications: The study's findings provide insights that bear on both scholarship and pedagogical design aimed at promoting substantive interdisciplinary learning with CT, and, critically, navigating potential tensions that can arise within it.

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1. Introduction

Advocates for integrating approaches to problem solving rooted in computer science within K12 schooling have historically framed their project as not simply focused on

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teaching these competencies in a vacuum, but have instead pointed to the increasing role of computing in solving complex interdisciplinary problems. In Jeanette Wing's advocacy for making Computational Thinking "an integral part of childhood education" (Wing, 2008, p. 3720) she argued for its relevance in addressing problems not just within the field of computer science, but rather problems across all domains of inquiry such as biologists using computational modeling to sequence the human genome or economists using algorithms to help patients find optimal organ donors. And, she shared an important caveat, that "there are many cultural, economic, political and social barriers in realizing this vision" (p. 3722).

Wing's vision, and caveat, have animated the efforts of educators, researchers, and policy makers to design K12 instructional opportunities that integrate CT directly with other school subjects (Grover & Pea, 2013; Yadav et al., 2019), with a focus on addressing barriers to implementation. These efforts span a wide range of work to design integration frameworks (Barr & Stephenson, 2011; Brennan & Resnick, 2012; Güven & Gulbahar, 2020; Ketelhut & Cabrera, 2020; Manfra et al., 2022; Weintrop et al., 2016), learning technologies (Blikstein & Wilensky, 2009; Eisenberg, 2002; Guzdial & Shreiner, 2021; Sengupta et al., 2013), pedagogical strategies (Lye & Koh, 2014), curricula (Neumann & Dion, 2021; Schanzer et al., 2015) and assessments (Clarke-Midura et al., 2021; Cutumisu et al., 2019; Grover, 2021; Tang et al., 2020), to support viable learning, as well as efforts to develop effective teacher training (Coenraad et al., 2022; Hestness et al., 2018; Israel et al., 2015; McGinnis et al., 2019) and create institutional will for integration of CT within existing disciplines (Santo et al., 2021, 2023).

While these efforts are critical, we argue that to better equip educators to integrate CT into core disciplines, Wing's caveat needs to be extended even further to include not just institutional and implementation barriers, but also epistemic tensions that can emerge when multiple disciplines are brought into contact. Addressing these questions requires scholars and designers to attend to the tensions that emerge when heterogenous epistemic disciplines come into contact – tensions that can lead to missed opportunities and/or harms in the learning process. Existing scholarship has noted how in K12 science classrooms, Western-dominant epistemologies that focus on taxonomical classification have actively silenced alternative and indigenous perspectives that center ecological relationships (Warren et al., 2020). Similarly, in professional contexts such as public policy, epistemologies rooted in micro-economics (e.g. data-driven cost-benefit analysis) have dominated humanistic epistemologies, leading to a prioritization of efficiency over equality within policy decision-making (Berman, 2022). Given these possibilities of harm, scholarship and design efforts focused on integrated CT should aim to support teachers and students to navigate multiple epistemologies in ways that not only surface novel possibilities for problem solving, but also avoid retrenchment of existing social harms through misapplication of epistemic tools and practices.

The phenomenon of epistemic tensions related to CT is understudied, with little guidance for educators on how to recognize them or to support learners to productively navigate them. Utilizing the context of pedagogical integration of computational thinking (CT) practices (Grover & Pea, 2013) within K12 language arts, social studies, and arts instruction, this manuscript presents findings from an empirical study of expert perspectives that surfaced epistemic tensions between CT and humanities and arts disciplines, as well as some directions for navigating them. Identifying epistemic tensions within the context of CT integration into K12 humanities and arts disciplines is particularly timely and relevant to policy and practice given growing nation-wide efforts to implement comprehensive computing education under the banner of Computer Science for All (Guzdial, 2016; Santo et al., 2019; Vogel et al., 2017; White House Office of the Press Secretary, 2016), which is often inclusive of efforts to integrate CT directly into the humanities and arts (Neumann & Dion, 2021; Santo et al., 2021).

The study's central questions are: What perceived tensions exist between epistemologies of K12 humanities disciplines – social studies, language arts, and arts – and those associated with computational thinking within pedagogical contexts? Secondarily, we ask: How might such epistemic tensions be addressed? In order to address these questions, we draw on data collected in the context of a Delphi study (Linstone & Turoff, 1975) wherein 43 experts in K12 social studies, language arts, and arts instruction were consulted to surface their perspectives on potential intersections between their core disciplines and computational thinking practices.

Based on an analysis of over 20 hours of focus group discussions and over 300 text-based expert annotations on potential approaches to integrating CT into K12 humanities and arts disciplines, our analysis found 5 epistemic tensions: (1) contextual reductionism, (2) procedural reductionism, (3) epistemic chauvinism, (4) threats to epistemic identities, and (5) epistemic convergence. Contextual reductionism relates to concerns that losses of nuance, particularity, and ambiguity could result from CT's valuation of abstraction, quantification, modeling, pattern recognition, and prediction practices. Procedural reductionism relates to concerns that CT's focus on algorithms could result in problematic reduction of complex epistemic practices into sets of tractable steps. Epistemic chauvinism relates to the elevation of CT epistemologies at the expense of those related to a focal discipline in ways that devalue or sideline existing ways of knowing and doing within a discipline. Threats to epistemic identities relate to concerns that cultural and historical identities associated with humanities and arts epistemologies could be under threat during integration of computational thinking epistemologies. Finally, epistemic convergence relates to concerns that overlaps and similarities in epistemologies associated with CT and those of a focal discipline could lead to superficial semantic shifts and "reskinning" of existing practices, rather than substantive extensions into authentic interdisciplinary learning.

Our findings explore these tensions in more depth, sharing perspectives from K12 humanities and arts experts as to their nature and possible harms within classroom contexts. Additionally, we include more preliminary findings on potential approaches to addressing or otherwise navigating these tensions. We close with further discussion of the dynamics across these epistemic tensions, and how the nature of the tensions might inform responses to them.

2. Background

To ground our inquiry, we first explore the ways that scholars have approached barriers to integration of computational thinking within K12 disciplinary learning. We then consider epistemological dynamics both in terms of opportunities for interdisciplinarity and epistemic heterogeneity linked to integration of CT, as well as epistemic tensions and harms.

2.1. Institutional change dynamics in integrating computational thinking in K12 classrooms

Scholars focused on integrating computational thinking directly into core K12 disciplines such as Social Studies and Math have documented the wide-ranging institutional change dynamics of this integrated approach. Proponents of this approach argue that integration of CT into K12 core disciplines, rather than offering CT solely as a standalone elective, helps to ensure that CT will be widely accessible to all students (Weintrop et al., 2016), a goal upheld by the broader computer science for all movement (DeLyser, 2018; Guzdial, 2016).

Yet, scholars have cautioned that in order to achieve this goal of equitable access to computer science education through an integrated approach, a number of institutional challenges must be addressed. These include the need to specify student learning pathways and outcomes, design new curriculum, recruit students, assess student learning, ensure equitable approaches, and prepare teachers (Grover & Pea, 2013). Researchers have further argued that integrating computational thinking directly into core disciplines raises additional difficulties around preparing teachers and pre-service teachers to develop knowledge of computational thinking, comfort with pedagogies that support computational thinking integration, and competency with technology tools and platforms that support pedagogies of CT (Mouza et al., 2017). Further still, as CT becomes integrated in K12 disciplines, an additional issue becomes salient: how to support teachers and students in seeing the relevance of CT in Humanities and Arts-based disciplines (Ray et al., 2022; Repenning et al., 2020; Santo et al., 2021, 2023). These institutional challenges tend to run into the practical difficulties of limitations in available time, resources, and expertise for implementing new initiatives (Israel et al., 2015).

Scholars have directly addressed these institutional challenges through a variety of efforts. Scholars have developed frameworks to map various dimensions of computational thinking across different K12 subject areas (Barr & Stephenson, 2011; Brennan & Resnick, 2012; Güven & Gulbahar, 2020; Ketelhut & Cabrera, 2020; Manfra et al., 2022; Weintrop et al., 2016), designed learning environments and tools to situate computational thinking within other disciplines (Blikstein & Wilensky, 2009; Eisenberg, 2002; Guzdial & Shreiner, 2021; Sengupta et al., 2013), suggested pedagogical strategies specifically for integrated CT (Lye & Koh, 2014) and created assessments that operationalize specific dimensions of CT (Clarke-Midura et al., 2021; Cutumisu et al., 2019; Grover, 2021; Tang et al., 2020). Furthermore, scholars have provided guidance for helping classroom humanities and arts teachers develop their familiarity and comfort with CT, project-based pedagogies, and interdisciplinary curriculum design (Neumann & Dion, 2021). These frameworks, learning environments, and practitioner guidance are valuable for making the integration of CT into K12 instructional systems more practical for educators and more concrete for learners.

2.2. Epistemological dynamics in integrating computational thinking in K12 classrooms

Although the opportunities and challenges of the integrated approach to computational thinking are well documented at the institutional level, much less is known about the opportunities and tensions of this approach at the epistemological level.

The epistemic dimension of a discipline can be understood as the discipline's specific "style of reasoning" (Hacking, 1992; Sciortino, 2017). As Elizabeth Popp Berman (2022) elaborates, "styles of reasoning are not scientific paradigms, nor are they particular theories, or models. Instead, they are collections of orienting concepts, ways of thinking about problems, causal assumptions, and approaches to methodology" (p. 5). Characterizing the epistemic dimension of a discipline, then, can involve attending to the methods that those working in the discipline use to generate knowledge, as well as closely examining the assumptions underlying these methods. Inquiry methods can be examined to unearth the various decisions that get embedded in them – the ways inquirers conceive of, design for, and conduct their study, as well as how they justify their conclusions. Further embedded within this array of decisions are assumptions such as what it means to know, what it takes to justify knowledge, the purpose of generating knowledge, and what makes the inquiry process valuable or worthwhile (Reynante et al., 2020). In short, the epistemic dimension of a discipline can be thought of as the methodological issues, questions, and assumptions disciplinary practitioners bring to their knowledge production practice. Similar to Hacking's notion of a "style of reasoning" (1992), Kelly & Licona (2018) define this epistemological dimension of a discipline as the "specific ways members of a community propose, evaluate, and legitimize knowledge claims within a disciplinary framework" (Kelly & Licona, 2018, p. 99).

As an example, we can see specific styles of reasoning at play in the interactions between K12 teachers from different disciplines during a weeklong workshop in which they were tasked to co-design an original transdisciplinary lesson that integrates computation, art, and science (Finch et al., 2021). While collaborating to build an artistic paper lantern that used sensors to dynamically display data from a garden, a science teacher thought about this challenge in terms of scientific fidelity and asked questions about how to make the lantern display plant processes such as photosynthesis. An art teacher, by contrast, thought about this same challenge in terms of the aesthetic materiality of the paper lantern and asked questions about how the material might respond to ink and brush strokes, how it would take up space, and what it might look like from different angles. In what can be seen as a productive example of interdisciplinarity and epistemic heterogeneity, Finch et al. (2021) report that these teachers appreciated and mutually privileged each other's different perspectives.

2.2.1. Opportunities for interdisciplinarity and epistemic heterogeneity

Scholars and advocates focused on integrating computational thinking with existing K12 disciplines point to two opportunities of this approach at the epistemological level: interdisciplinary learning, and epistemic heterogeneity. First, integrating CT into core disciplines, rather than as a standalone course, provides students with opportunities to readily and explicitly make connections across multiple disciplinary and everyday practices and ideas. These connections can deepen students' capacity for transdisciplinary sensemaking by broadening the lenses and methods they use to explore phenomena or solve problems (Finch et al., 2020). Furthermore, when CT is integrated into core disciplines, the phenomena students explore and the problems they solve can be inspired by real-world issues and applications that currently and genuinely occur in professional interdisciplinary contexts such as bioinformatics and computational statistics (Weintrop et al., 2016).

Second, scholars argue that learning environments that integrate computing directly into core K12 disciplines such as art and science promote epistemic heterogeneity (Pierson et al., 2022) wherein participation in those disciplines becomes more inclusive by offering students new ways to produce and express knowledge within them (Finch et al., 2020; Peppler & Wohlwend, 2017). Under this vision, rather than being limited to the canonical representations of a given discipline such as using bar graphs in science to show the relationship of variables, students can use computing to design interactive artifacts and simulations to creatively convey the same information. This can be especially beneficial for students whose practices of generating and representing knowledge markedly differ from the canonical forms that have become settled within a core K12 discipline (Bang & Medin, 2010; Finch et al., 2020)

2.2.2. Challenges of epistemic tensions

To best support these opportunities for interdisciplinary learning and epistemological heterogeneity, it will be crucial to identify the epistemological challenges that teachers must navigate with their students when integrating CT with K12 disciplines such as the Humanities and the Arts. Yet, the epistemological challenges are under-theorized and under-studied, leaving practitioners with little guidance for how to identify them and productively navigate them. The lack of empirical research in this area may be an artifact of how new this integrated approach to CT is, especially within non-STEM K12 disciplines. Evidence that epistemological tensions (epistemic tensions for short) exist between the different "styles of reasoning" of CT and the Humanities and Arts can be found in contexts outside of K12. This evidence alongside the anecdotal intimations of scholars, their colleagues, and their informants who voice their concern and caution about the epistemic tensions of this work provides a starting point for the current study which directly focuses on epistemic tensions in K12 contexts as its phenomenon of interest.

Reflecting across a range of empirical studies of children and college-level students learning to program, Turkle and Papert (1990) argued that the dominant ideology within computing culture itself placed students at odds with their own preferred approaches to generate knowledge. Whereas many of the learners Turkle and Papert (1990) observed were able to program successfully with computers through an epistemic approach characterized by creative exploration and a close personal relationship to their programs, they often felt a "pressure to conform to an officially imposed style" characterized by top-down planning and a distant impersonal relationship to their programs (p. 131).

These different approaches to generating knowledge became a paramount tension for post-secondary students in interdisciplinary contexts that brought together computational thinking and arts-based design (Turkle, 2009). Turkle (2009) also chronicled the "new design epistemologies" that took shape at MIT in the 1980s as architecture faculty and students were just beginning to use computer programs to enhance their design process (p. 11). Although computational simulations allowed students to easily manipulate and tinker with the form and shape of buildings from multiple points of view, Turkle (2009) found that the architecture students felt the computational simulations infringed upon the satisfaction they received from creating hand drawings or building cardboard models – tactile modalities better suited to expressing their personality and identities as artists. Indeed, some architecture students saw real harm to their identities as professional artists, so much so that they began to perform "selective ignorance" around learning programming in order to retain their identity as an artist rather than as computer programmer. In the presence of computational simulations, these students began to create a "simulation-free zone" around their drawing process which they saw as a "sacred space" (p. 21). This example shows that different styles of reasoning are not always mutually appreciated and can even detract from a group's disciplinary knowledge production processes and identities.

Further still, rather than fostering a more authentic interdisciplinary engagement with computing and architecture, the faculty worried that the students' final designs lacked (a) direction, inasmuch as students made "changes for change's sake", (b) originality, inasmuch as students gravitated toward the simulations' default designs, and (c) artistry, inasmuch as students' computer print-outs lacked the flourishes and color-palette of hand-drawn designs. Worse yet, the computer program, detached from the topography of the actual building site, led students into untenable designs, such as the case of a road that was drawn on a slope that was in reality too steep to support it. These design examples highlight that computing is not always supportive of disciplinary practices, can misdirect novices with false starts, and can lead to harmful, even potentially dangerous, outcomes if applied directly and uncritically to real-world practice.

Such examples of epistemic tensions are not isolated to the integration of computer simulations within the field of architecture and design. In their empirical study of epistemic identities in interdisciplinary labs, Osbeck and Nersessian (2017) found that lab members' identity work was entangled with their knowledge production work, as they navigated conflicting ideologies, multiple norms and standards, and theoretical frameworks "specific to disciplinary specialties". As Richard Lehrer (2021), citing this study in his chapter Promoting Transdisciplinary Epistemic Dialogues, puts it: "a close inspection of professional interdisciplinary practice affirms that new disciplines do not emerge seamlessly as a homogenized blend of existing fields". In short, epistemic tensions exist along the seams of interdisciplinary integrations.

Alongside these examples chronicled by Turkle, other scholars have documented their own concerns as well as those of their colleagues and study informants about the epistemological harms that can result if these epistemic tensions are left unaddressed. Hemmendinger (2010) in his opinion piece "A Plea for Modesty", warns that efforts to integrate computational thinking take on an "imperialistic flavor" when practices that are common to other disciplines such as building models or finding and correcting errors are suddenly claimed to be exclusively the territory of computational thinking (p. 5). For Hemmendinger (2010) this "imperialistic flavor" of integrated CT rhetoric helps explain why Denning's (2009) colleague in another field remarked, "You computer scientists are hungry! First you wanted us to take your courses on literacy and fluency. Now you want us to think like you!" (p. 5). This "imperialistic flavor" may also explain the vivid language used by an informant in another study who directed an interdisciplinary center for arts, computing, and engineering, and warned of the harms caused when "practitioners who are firmly rooted in one discipline, and have a strong internal sense of [its] authority – who feel that they hold the master discourse, as it were – go on looting expeditions to grab some subject matter or [methodology] from some outlying discipline and drag it back to mine or exploit or reprocess it" (Barry & Born, 2013, p. 12).

These pointed remarks raise deep and fundamental issues that are worth addressing: what kinds of epistemic tensions emerge when two different disciplines are brought together in classroom settings? What harms might these tensions cause? And how can educators effectively design and implement integrated learning environments that productively navigate these tensions?

Hemmendinger (2010) offers one partial answer to these questions in the context of integrated CT. He urges educators to replace "grand territorial claims" such as, for example, abstraction is computational thinking, with more modest claims such as "abstraction is one property of computational thinking (and may also be a property of many other sorts of thinking)" (p. 5, 6). Yet, more research is needed to better anticipate the types of epistemic tensions that teachers and students may contend with in integrated CT learning environments. Scholars have documented that when epistemic tensions are left unaddressed in the K12 classroom, even in the context of a single discipline, epistemic harms for students can ensue.

2.2.3. Epistemic harms

Beth Warren et al. (2020) analyze an example of the epistemic tensions and associated harms that arise in a 7th grade Life Sciences classroom setting. During a classroom activity in which students were tasked to categorize phenomena such as jellyfish, rain, and the sun as either living or nonliving, two different styles of reasoning – what the authors term onto-epistemic framings – came into contact. The default or "settled" style of reasoning expressed by a white student and enforced by the teacher in this activity worked to classify nature into essential categories using a binary logic. An African-American student offered a style of reasoning that worked to conceptualize nature as a dynamic and ecological system of relations that defied the two categories of living and non-living. Through this more relational perspective, the student raised new questions, such as "how does the sun contribute to the livelihood of a flower?". Unfortunately, these questions, and the style of reasoning that generated them, were actively silenced by the teacher and students who operated from the default binary style of reasoning.

This scene is not an isolated incident, but a reflection of historical and ongoing practices in which certain forms of knowledge production are dismissed and rendered illegitimate, unless they are formulated in ways acceptable to those who uphold the dominant styles of reasoning (Morrison, 1989). Scholars have documented the various machinations by which these harms, in the form of epistemic injustices, are exercised in real world knowledge production processes (Fricker, 2007), in curated sites of learning (Stroupe, 2022), in intentionally designed multidisciplinary communities of practice (Mäkinen, 2022), and in high-stakes contexts of public policy-making (Berman, 2022).

For example, Albert, Paradis, and Kuper (2015) documented the negative experiences and feelings that emerged for social scientists and humanists working in a medical research environment. The social scientists and humanists felt that their contributions were not given full or equal value by the health researchers who used different disciplinary criteria to evaluate research practices and knowledge production, which resulted in feelings of dissonance, frustration, and disappointment. Nearly all of the 29 social scientists and humanists participating in this study reported negative consequences to their well-being and livelihood such as pressure to change their research practices against their will, social isolation and withdrawal from academia altogether, or impasses to getting promoted (Albert et al., 2015). Salmela & Mäki (2017) interpret this case as an example of epistemic injustice inasmuch as the social scientists and humanists "are evaluated by medical researchers whom they perceive to lack the expertise to soundly evaluate their work".

Given the existence of epistemic tensions, as well as the harms that befall students when epistemic tensions are left unaddressed in K12 contexts, it behooves the field to adequately identify the epistemic tensions that emerge in an integrated CT approach to better equip teachers, curriculum developers and others in the educational system with strategies for navigating these tensions and minimizing potential harms for students.

3. Methods

3.1. Research questions

Drawing on the considerations outlined above regarding how interactions among distinct epistemologies can play out, along with the broader trends towards integrating computational thinking specifically within K12 classroom settings, this study aims to address the following research questions: RQ1: What perceived tensions exist between epistemologies of K12 humanities and arts disciplines – social studies, language arts, and arts – and those associated with computational thinking within pedagogical contexts? RQ2: How might such epistemic tensions be addressed?

In order to address these questions, we draw on data collected in the context of a Delphi study (Linstone & Turoff, 1975) wherein experts, including researchers, curriculum developers, and educators in K12 social studies, language arts, and arts instruction were consulted to surface their perspectives on potential intersections between these disciplines and computational thinking practices.

The central data for the study comes from a series of focus group conversations that took place as part of the larger Delphi study, the original intention of which was to advance knowledge and generate ontological innovation (DiSessa & Cobb, 2004) around areas of promising overlap between CT and K12 humanities pedagogy – ways that CT practices might enhance and extend existing instruction, centering explicitly on advancing the goals of a given discipline rather than those associated with CT. However, it became evident over the course of the data collection process that many participating experts saw fundamental differences between their discipline in and of itself and computational thinking. Going beyond implementation-related concerns (e.g. teacher capacity, technology access, limited time for classroom integration), these perspectives related to core epistemic values and practices that would come into contact within the context of interdisciplinary pedagogies bridging CT and humanities. These perspectives elevated for the research team the need to investigate the nature of epistemic tensions, and possibilities for addressing them, surfaced by experts in the Delphi study during its focus groups.

3.2. Delphi method

Delphi studies utilize expert consultation as a means to gather judgements related to a particular topic, assess and compare across expert perspectives that may not be currently documented in extant literature, and generate new ideas related to a topic (Franklin & Hart, 2007). We deemed the utilization of the Delphi method appropriate in the context of the larger study as, noted above, while there have been formal articulations on the relationship between pedagogy in disciplines like science and mathematics and computational thinking (Weintrop et al., 2016), related literature in the humanities is sparse, and more actively focuses on specific possibilities for integration without exploration of broader epistemic relationships between CT and these disciplines as a whole (Güven & Gulbahar, 2020; Jacob et al., 2022; Leonard et al., 2021; Manfra et al., 2022; Steinberg et al., 2022; Vogel et al., 2020). Additionally, the period of study occurred within the larger context of the height of the global COVID-19 pandemic, requiring our project team to shift its methods after receiving feedback from teacher partners that direct implementation utilizing design-based research methods, as we had planned, would not be viable given the pressures they faced. The Delphi approach was suitable as a practical and safe, if methodologically distinct, alternative in that it both did not disrupt existing classrooms during a challenging historical moment and also lent itself to virtual participation such that participants could reduce health risks.

3.3. Participants

We engaged a total of 43 participants in the enactment of the Delphi study focus groups —14 with expertise in K12 social studies (SS) instruction, 16 with expertise in K12 Language Arts (LA) instruction, and 13 with expertise in K12 Arts instruction. Aiming to draw on expertise that spanned direct experience in instructional settings as well as educational scholarship in focal disciplines, the study sample included 10 classroom teachers, 10 instructional specialists (coaches, curriculum developers, district or state level instructional leaders) and 23 education researchers based in institutions of higher education or non-profit research institutions. Additionally, we aimed to balance the sample with individuals that had experience with the intersection of their core discipline and computational thinking (SS = 5, LA = 9, Arts = 8) with those that had no experience with computational thinking or computer science (SS = 9, LA = 7, Arts = 5). We purposefully balanced the individuals from each of the three disciplines with and without CT/CS background to generate a robust discussion of whether and how the design principles could support middle school teachers' disciplinary instructional goals. Participation in the Delphi study involved three components – engagement in a short capacity building session around CT, participation in focus group discussions exploring discipline-specific CT integration design principles, and completion of a survey related to these CT integration design principles. The current manuscript does not report on data related to the survey. Details related to the capacity building sessions and focus groups are outlined below.

3.4. Participant capacity building

All participants engaged in a 90-minute capacity building session facilitated by our research team that provided a summary and overview of core ideas related to computational thinking. As participants differed when it came to their degree of prior knowledge around CT, the goal of the capacity building session was to establish some degree, even if imperfect, of shared understanding of CT among participants that could support later deliberation around the intersection of CT and their focal disciplines. During the session, we shared the project's working definition of CT, "formulating problems in a way that enables us to use a computer and other tools to help solve them" (ISTE and CSTA, 2011), and engaged participants in activities that aimed to support understanding of core CT practices, rooted in this definition, of algorithms, abstraction, and patterns and data. Appendix A contains an agenda and overview of the activities implemented during the capacity building session.

3.5. Focus groups

Between 1–2 weeks after the capacity building session, participants engaged in a two hour focus group with other participants in their focal discipline. The focus groups involved two elements. The first, lasting approximately 40 minutes, centered on open ideation, involved a mix of silent responses to prompts in digital documents and whole and small group discussions related to (1) their perceptions of central pedagogical challenges and opportunities facing their focal discipline generally and (2) potential intersections of their focal discipline with computational thinking. The second element, lasting approximately 80 minutes, involved a review of design principles for integrating computational thinking instructional approaches into their focal discipline. These design principles were developed by the research team through previous reviews of literature and participatory design with CT experts and classroom teachers (Caskurlu et al., 2022). Examples of design principles are included below in Table 1, and the full lists of design principles reviewed by experts can be found in Appendix B.

During the review of these design principles, participants first left feedback in digital documents and then engaged in small group discussions related to them. In this context, participants were actively encouraged to, as they saw fit, take issue with (1) the clarity of the approaches, (2) their appropriateness and feasibility within classroom settings, and (3) the potential, or lack thereof, for consequential impact on teaching and learning within the focal discipline.

We recognize that the short amount of time devoted to the capacity building for those individuals that did not have CT background could be a limitation for their ability to reason through the opportunities and tensions between the home discipline and computing paradigms. Nevertheless, we contend that the deliberate inclusion of individuals possessing both disciplinary and CT knowledge, juxtaposed with those solely with

Table 1. Examples of CT integration design principles presented to experts during delphi study focus groups. Appendix B includes full lists of reviewed design principles.

Example CT Integration Design Principle	Discipline
Model social, historical, or political phenomena through computational or non-computational means to reduce complexities and highlight relationships.	Social Studies
Create data representations in order to understand the use and implications of abstraction within social, political, or historical phenomenon	Social Studies
Create artistic works (computational or non-computational) using algorithmic processes or tools	Arts
Create artistic works that incorporate sensory effects (e.g. movement, light, or audio) through use of physical computing	Arts
Examine a text through patterns and quantitative literary data.	Language Arts
Prepare to write narrative texts by creating flowcharts, storyboards, or other representational forms.	Language Arts

disciplinary expertise, fostered a robust discussion within the focus groups. This enhanced the groups' capacity to flexibly adapt their thinking across multiple paradigms.

3.6. Data

The analysis presented in this manuscript focuses centrally on two forms of qualitative data gathered in the context of the Delphi study focus groups: recorded transcripts of focus group whole group and breakout discussions, and textual comments left by participants on CT integration design principles documents (see Appendix B). While each of the six focus groups (two per discipline) was two hours, inclusive of parallel breakout discussions, a total of ~20.5 hours of discussion (~5.5 hours of whole group, ~15 hours of breakout groups), was transcribed and coded. Additionally, a total of 312 comments on the CT integration design principles – submitted using the "comment" feature on Google Docs – were included in this analysis (135 comments for Language Arts, 106 comments for Social Studies, 71 comments for Arts).

3.7. Epistemic orientations of authors

Our analytic approach was loosely informed by a broader set of theoretical stances related to epistemology held by the study authors, including perspectives from Analytic philosophy, Science and Technology Studies (STS), and Cultural-Historical Activity Theory (CHAT). While these orientations were not directly operationalized into the analytic approach outlined in the next section, they represent a set of theoretical foundations, and attendant commitments, that were woven into our processes of analytic sensemaking and framed how we thought about the nature of epistemologies and potential for epistemic tensions.

First, the project of epistemology, a subdomain of analytic philosophy, has been to specify the distinctive characteristics of various modes of knowledge production and knowledge claims that are organized around different interests (explaining phenomenon, interpreting meaning, having a self-revelation) (Habermas, 1972). This approach informed how we considered the tensions that could presumably come into play when different epistemologies come into contact purely at a conceptual, one might even say ahistorical, level. It directed our analytic lens towards the possibilities that knowledge practices, regardless of issues of culture, setting, and context, might be at odds with each other.

Secondly, the domain of Science and Technology Studies (STS) uses theoretical approaches established in the social sciences such as history and anthropology to closely analyze knowledge-production processes via social interactions between epistemic disciplines in cross-disciplinary collaborations (Barry & Born, 2013). The STS theoretical orientation kept us oriented towards not just how epistemic tensions might emerge at a conceptual level, but how they emerge readily and routinely, with real-world consequences and impact, in a variety of social and historical contexts as epistemologies come into contact *in situ*.

Lastly, Cultural-Historical Activity Theory also analyzes real-world settings similar to STS, but does so at the unit of analysis of an activity system (Engeström, 1987), and often with the aim of remediating and improving upon the design of the activity system. The models of activity system design and iteration range from Engeström's "Change

Laboratories" to models developed by scholars in the Learning Sciences that emphasize design-based research such as design experiments (Cobb et al., 2003), social design experiments (Gutiérrez & Jurow, 2016), and community-based design research (Bang et al., 2016). Our approach draws on this orientation here, aiming to identify contradictions experienced within and between activity systems (i.e. epistemic tensions between disciplines) that might become focal points for advancing beyond the current limitations of existing systems and generate previously unconsidered solutions (Engeström & Sannino, 2010). We see this epistemic orientation as pertinent to and motivating the broader study's interests of better informing designers and educators to adequately attune to and respond to the types of epistemic tensions, and resolutions, that might emerge in designed integrated computational thinking activity systems.

3.8. Analysis

The foundation of the study's analytic process entailed iterative coding of the 20.5 hours of focus group transcripts and the 312 written participant comments through the lens of the research questions (see section 3.1), the first focused on identifying epistemic tensions, and the second focused on identifying potential resolutions. Our own epistemic orientations, noted in the prior section, while broadly informing the sensemaking process, were not used actively in the coding process. Rather, with the research questions as the core frame, we then utilized a grounded theory approach (Glaser & Strauss, 1967; Strauss & Corbin, 1997), to analyze the full data corpus.

To generate our findings, one member of the research team first conducted "open coding" of the data corpus to surface any data that could be inferred as speaking to the study research questions, identifying instances of data that might indicate either epistemic tensions within the context of K12 learning environments that integrate computational thinking with the humanities or resolutions to such tensions. Following this initial open coding, the research team met routinely to review data and initial codes that aimed to make distinctions within the data, condensing, combining, clarifying, disambiguating, and disaggregating constructs in order to arrive at conceptual clarity, orthogonality, and specificity. This process was used to generate a codebook which contained definitions and examples for each code as well as the structure of codes and subcodes. These routine data analysis meetings allowed the research team to surface and resolve differences of interpretation as well as border cases, which helped to further refine the coding scheme.

During the process of developing the initial coding scheme, the team then engaged in theoretical sensitization around potential codes, discussing code-concepts in the context of extant literature to help clarify code definitions. Broadly, the process of theoretical sensitization affirmed the coding scheme that had been developed by our research team up to that point. Through this process the study data was analyzed using both inductive and deductive approaches to sensemaking (Strauss & Corbin, 1997).

After a further round of refinement of the codebook, the coding scheme stabilized, and our research team re-coded the full data corpus. This final coding scheme constitutes the core categories of our findings (see Table 2 in section 4 for code categories and associated definitions). With the full data corpus coded, the team then engaged in data reduction – identifying the clearest and lowest inference examples within the data related to each of the analytic codes. This supported the generation of five analytic memos, one for each the epistemic tension codes identified, as well as an additional memo related to possible resolutions of tensions. These memos acted as the basis for the findings presented below.

While the focus of our analysis is not based on the frequency of code occurrence generally or across participant backgrounds but rather on the content and variety of tensions discussed, data related to epistemic tensions did surface in repeated and patterned ways across the data corpus, warranting our perspective that this was not an outlying but rather a persistent phenomenon. With the exception of one tension (Threats to Epistemic Identities) that was only raised by arts experts, each of the tensions we identified was raised during focus groups across all three focal disciplines. Additionally, a majority of participants ($n = 24$, 56%) raised at least one of the tensions found in the analysis, and this group was fairly evenly split between participants with prior expertise in computer science and computational thinking ($n = 13$) and those without it ($n = 11$). Appendix C includes a breakdown of the participants who voiced each of the tensions by discipline and prior CT experience.

4. Findings: epistemic tensions between computational thinking and K12 humanities and arts and possible resolutions

In this section, we outline the central tensions that experts in K12 humanities and arts disciplines – language arts, social studies, and arts – perceived between the epistemologies of their focal disciplines and that of Computational Thinking (CT) that could arise in pedagogical contexts. Our analysis found 5 epistemic tensions: (1) contextual reductionism, (2) procedural reductionism, (3) epistemic chauvinism, (4) threats to epistemic identities, and (5) epistemic convergence. The table below provides an overview and brief definitions of these tensions, and subsections that follow offer findings related to each. Finally, we also found that participants voiced a number of possible directions for resolving or otherwise addressing epistemic tensions in this context.

Table 2. Epistemic tensions expressed by delphi study experts related to integration of computational thinking into humanities and arts disciplinary pedagogy.

Epistemic Tension	Definition
Contextual Reductionism	Concerns that losses of nuance, particularity, and ambiguity around, for example, historical events or pieces of literature could result from CT's valuation of abstraction, quantification, modeling, pattern recognition, and prediction practices.
Procedural Reductionism	Concerns that CT's focus on algorithms could result in problematic reduction of complex epistemic practices into sets of tractable steps. This tension was often expressed in relation to what was seen as inappropriate application of algorithmic logics to knowledge production.
Epistemic Chauvinism	Elevation of CT epistemologies at the expense of those related to a focal discipline in ways that devalue or sideline existing ways of knowing within a discipline.
Threats to Epistemic Identities	Concerns that cultural and historical identities associated with humanities and arts epistemologies—their epistemological 'ways of being', so to speak—could be under threat during integration of CT epistemologies.
Epistemic Convergence	Concerns that overlaps and similarities in epistemologies associated with CT and those of a focal discipline could lead to superficial semantic shifts and "reskinning" of existing disciplinary practices, rather than substantive extensions into authentic interdisciplinary learning.

4.1. Contextual reductionism

Participants, especially experts in social studies and language arts pedagogy, raised concerns around **contextual reductionism** that could result from integrating CT with their focal disciplines. These concerns touched on themes of loss of nuance, particularity, and ambiguity around, for example, historical events or pieces of literature, with participants linking loss of context to CT's focus on abstraction, quantification, modeling, pattern recognition, and prediction.

In the social studies Delphi group, during a discussion of CT integration approaches outlined in a design principle document that the experts had just reviewed, one expert shared what might be characterized as a more general anxiety around this issue:

> "Context is so important in history, and there were a couple of places [in the design principles] where I just became worried that it would be lost with some of the computational approaches. I don't think that that throws computational approaches out the window, but I think that that needs to be really factored in when we're thinking about applying computing to the study of the past, and the present for that matter". -SS.2

Expanding out this concern, at another point in the conversation a participant linked tensions around contextual reductionism to broader trends both in society but also within the professional practice of historians around the limits of modeling and prediction, noting ways these practices intersected with ways of knowing valued by historians. First, he pointed to what he characterized as failures of predictive polling in recent US presidential elections. Then, he discussed a prominent social scientist, one he saw as controversial, who engages in mathematical modeling and prediction based on large-scale historical data sets. Specifically, he contrasted various perspectives around what can be known and ways of thinking about history:

> "[His work is] very compelling because he's trying to map out these patterns. And this is a real difference in the way we [historians] think about history, because history is the outlier, the particular, the humanitarian, you know, the 'choice and agency history' versus the 'patterned history'. And I think it's really interesting. But you know, I think you're definitely staking out an arena within this type of study by doing this kind of work that's not unproblematic, let's just say that". -SS.1

The participant explicitly links ideas around contextual specificity – "the outlier, the particular" – to ways of understanding history that focus on contingency and possibility; "choice and agency history". He contrasts this with what he calls "patterned history", which he links to the example of the social scientist using historical data-sets to predict future events, seeing this as a "real difference in the way we [historians] think", and seeing that view of history as "not unproblematic", implying that it removes the possibility of agency for historical actors. Essentially, he saw such a view of history that removed context, contingency, and nuance in its project of using history to engage in prediction as one that could have negative consequences in terms of understanding and seeing possibilities around subjective agency.

In the language arts Delphi group, tensions around contextual reductionism arose during a discussion of "distant reading" practices – pedagogies that involve students engaging in textual analysis utilizing text quantification within language arts classrooms in ways that are distinct from "close reading" approaches (Lynch, 2019). One expert shared that she felt such an approach could limit possibilities for textual interpretation and become disconnected from larger objectives around textual analysis:

> "When you're studying character development, a character can be seen as kind and they can use many different words to use that, but if we're counting words . . . if we're looking just for the word 'kind', it's just very narrow that it doesn't really get to the objective of why we're doing it". -LA.4

Another participant, later in the discussion, expressed that she felt these approaches reduced the ways that students have to contend with ambiguity in the practice of textual interpretation:

> "It's [this approach is] taking away the ambiguity of English, of text, of comprehension, of analysis, and that makes our students much happier, they want the answer. They wanna know that they've got the right answer, they can answer it on the test, tell the teacher, tell the boss, and so we're taking away their comfort level of saying, "but there is no 'the answer', there are lots of answers. Now, let's figure out how you're going to figure out what your answer might be and how you can tell other people", and there's the output that they can get to. It's [about] how do you get kids to work and embrace ambiguity in the English classroom?" -LA.1

The participant here saw approaches of quantification-based textual analysis as being in tension with what she viewed as one of the productive, but perhaps uncomfortable, elements of more traditional epistemologies of textual analysis – the lack of a single, definitive interpretation. In her view, approaches of "distant reading" and quantification-based textual analysis could more easily result in students assuming more singular, non-ambiguous interpretations of texts.

4.2. Procedural reductionism

A second area of tension expressed especially by experts in both language arts and arts education related to ways that integrating CT practices could result in **procedural reductionism**: problematic reduction of complex epistemic practices into sets of tractable steps. This tension was often expressed in relation to applying algorithmic logics to knowledge production, approaches that in some cases aligned with internal critiques these experts had of existing procedural approaches to pedagogy within their discipline. For example, one LA expert shared:

> "I got nervous last week when we were at the orientation session, anytime I tried to think about computational thinking or algorithms in relation to writing, because I feel like I've spent a career trying to undo the algorithms of writing or funky things to get taught about writing as if there is a step that you follow". -LA.7

Echoing a common critique of the five paragraph essay (Warner, 2018), which this same expert referenced later as something "we end up trying to undo at the college level over and over and over again", the expression of this tension was linked by participants to ideas of knowledge production involving discrete "steps". One arts expert shared that he felt that art-making could be useful in introducing students to computational production – a priority of computing education – but that the inverse, of using algorithmic approaches to art-making, gave him pause:

> "It would be very useful for people to be introduced to computational thinking through artistic making, because sometimes it's a little bit more easy to grasp in hand-made things that we do, and if we're like, Oh, a pinch pot is created by this five step algorithm I think, Oh my gosh, that's so simple and not easy to understand, an algorithm is a complex term that people use and people don't know what it means, but on the other hand, how far do you wanna push that because even though there are algorithms within art, do you want people to start thinking that art really is about the algorithms, which it's not? There's a point there that has to be figured out". -A.4

Another Language Arts expert, one with a fair amount of experience with computing education, extended this perspective into what he deemed a more "philosophical" musing on the risks of "computational thinking" resulting in "thinking like a computer". He wrote the following during a group exercise:

> "CT is about demystifying, visibilizing our thinking processes, whether there are computers or not. [. . .] CT can become an inherently dehumanizing process. And ELA can be the opposite. Instead of thinking like a computer, we should push the computer to think more like a human". -LA.6

As he discussed this idea in the group, he extrapolated further on this point:

> "As I have been thinking about computational thinking [. . .], I'm kind of like the more we wanna try to think like a computer . . . Are we getting less human in that process? And I know this is way philosophical, but inherent to ELA is a much more humane discipline in that we want to highlight [that] all things are uniquely human, and when we try to adopt the thinking process like systematic, linear, like recursiveness and algorithmic problem solving . . . We problem solve all the time, we just don't necessarily go through a step-by-step process, and so are we inherently losing some of our humanity by becoming more like a machine?" -LA.6

While less concrete than concerns shared above about avoiding procedural approaches to writing essays or making art, he expressed what he saw as risks to epistemic values central to language arts, characterizing LA as a "humane discipline", and counterposing this with ways of thinking associated with algorithmic logics that are "systematic", "linear" or "recursive"-ones that follows discrete, often step-by-step, procedures to arrive at knowledge.

4.3. Epistemic chauvinism

The third tension surfaced by experts concerned how multiple epistemologies come into contact in ways that are mediated by larger cultural and political logics. These perspectives focused on risks of **epistemic chauvinism**—the elevation of CT epistemologies at the expense of those related to a focal discipline in ways that devalue or sideline existing epistemic commitments. Multiple experts situated this tension in the context of broader economic and institutional trends associated with devaluation of humanities and elevation of computing and STEM more broadly. As one expert described it:

> "[W]hen we got a new [university] president, I asked him a question at a university meeting . . . about how he saw the role of humanities and social science on the campus . . . and he literally said he saw them in service to STEM . . . I'm a dual degree in history, so those skills, those fields that we see as humanities fields, I think are often found as in service to other fields that seem to feel more defined, more weighty, more easily connected to skills and jobs". -LA.1

In pointing to this interaction with a powerful institutional actor – her university president – she highlights her personal experiences of policy discourses that elevate the positionality of STEM fields and subordinate that of humanities generally. She went on to share that she could easily imagine that bringing CT into, for instance, her English seminar, could lead to an elevation of its epistemic values over values of nuance and interpretation she associated with humanities as a result of CT's heightened power position institutionally.

Another expert working at the intersection of arts and computing education shared more direct experience of epistemic chauvinism that she linked to the larger economic and historical context in which she developed her own research and associated pedagogical designs:

> "Oftentimes, because the money is coming to us from the National Science Foundation or the world is speaking to us in terms of what is valued in computer science we forget to balance the scales, so to speak. And so we end up sort of subjugating the arts to computer science, and I catch myself doing it often. It's easy to do". -A.3

Pointing in this case to the priorities of funding bodies that are actively aiming to promote computing education, she shared that she herself has been guilty, so to speak, of elevating goals of computing pedagogy over those of arts within her work.

A third expert pointed more directly to what this kind of epistemic chauvinism looks like in practice, making a distinction between CT integration in Arts classrooms that is focused on tools/algorithms ("how we make art") and CT integration that authentically focuses on culture and heritage ("why we make art"). In this example, he contrasts two examples of CT integration, one about the algorithms used by artists to draw facial features and another about using a quilting algorithm to represent the artist's cultural heritage:

> "I think to me, the reason it [the quilting algorithm as CT] does work is you're tying it to a larger part of why we make art, representing the culture and heritage, not just the how we make art, and that's a huge kind of rift... We have an arts education world is there's many of us that really are trying to put it... I think that the field as a whole is trying to push what we make art about, or why humans make art and not just the tools" -A.4

He sees arts epistemology as exemplified by the reasons that we make art, in this case engaging in expression around cultural heritage, and the process of how we make art – exemplified in this case by the example of using algorithms to support drawing – as necessary but not the main priority of arts educators. He cautions against forms of CT integration that flip these priorities in ways that lead to epistemic chauvinism, where the elements of art that are deemed important as ones associated with algorithmic processes. Even if these elements might have a place in arts pedagogy, he sees them as ones that must be in service to broader goals that center the epistemic values of artistic practice.

4.4. Threats to epistemic identities

In considering how CT might be experienced in the pedagogical context of other disciplines, some experts highlighted tensions related to the broader cultural logics at play in distinct disciplinary contexts, and pointed to possible **threats to epistemic identities**: Concerns that cultural and historical identities associated with humanities and arts epistemologies – their epistemic "ways of being", so to speak – could be under threat during integration of computational thinking epistemologies.

One exchange highlighted the possibility of CT integration in arts classrooms acting as a "double-edged sword", creating new invitations for some students who do not identify with artistic epistemic practices, while at the same time alienating others who already do:

> "I see for people who are sort of more logical, left brain, it feels like computational thinking could actually be an accessible way into visual arts, especially if they are somebody who thinks that the visual arts are for creative people. [. . .] It could be an interesting entry point for people who don't feel comfortable with the arts at all". -A.5

> "On the other hand, people [who] want to evoke things without really meaning something, or I don't view my art as solving a problem or being at all logic-centered, it seems like it could be a stumbling block for them, something that is naturally very welcoming to those people . . . " -A.4

In the exchange, one arts expert points to possibilities of CT integration being an "entry point" for those less identified with the arts – those who might see themselves as "left brain" or "more logical", epistemic values she is associating with computation. A second arts expert, in turn, poses a natural counterpoint; that those who do not see themselves in this way, and enjoy the elements of artistic epistemologies that are not "logic-centered", might not welcome the presence of computational practices in artistic spaces where they had felt a sense of belonging.

Another arts expert shared direct empirical examples from her research experience with the use of the Scratch creative coding platform that highlighted her firsthand experience seeing these threats to epistemic identities in action. Pointing to an example of an afterschool program she had studied that had shifted from focusing on creative uses of Scratch and began elevating teaching computational thinking concepts, she shared how girls, in particular, had negative reactions to the shift:

> "We had after school programs where we did more typical kind of CS [Computer Science], like 'Today you're gonna learn the CS concepts using Scratch'. Any of the girls that could walk out, they did. 100% of them, every time. And these are girls that were highly committed [before the shift] that had made over 50 projects in Scratch and saw this as kind of their platform and that they were very central in it, so these two worlds are antithetical to each other". -A.3

The story from this expert, a researcher with extensive experience studying learning environments that bring together creative arts and computation, affirmed that threats to epistemic identities are not merely hypothetical. In the example, the shift to a more explicit emphasis on teaching computational concepts cut against the identities that girls in the afterschool program held related to artistic and creative practices, resulting in declines in participation in a context that had previously affirmed those identities.

4.5. Epistemic convergence

The final tension voiced by experts was distinct in that it did not stem from epistemic differences, but rather epistemic similarities. Our respondents shared that certain ways of operationalizing CT practices within the context of other disciplines in fact looked quite similar to existing epistemic practices in a core discipline's pedagogy in ways that were counter-productive. In essence, they voiced concerns around **epistemic convergence**, a phenomenon that could lead to superficial semantic shifts around and "reskinning" of existing disciplinary practices, rather than substantive extensions into authentic interdisciplinary learning.

Experts pointed to possibilities of epistemic convergence especially in the context of certain CT integration approaches within Language Arts classrooms. Specifically, various respondents characterized approaches that utilized algorithmic, ruled-based methods for analyzing texts as well as practices of modeling and abstraction, such as flow charts or storyboarding, that support reading and writing processes, as ones that already exist in Language Arts classrooms under different names. For example, one LA expert wrote the following in response to the prompt "What are ways you can imagine instruction looking when CT is integrated into ELA?":

> "I think there is a tension between wanting to incorporate CT into ELA in a way that is just renaming what ELA teachers are already doing. . . For example, the formulaic intro paragraph Hook, Background, Thesis Statement, can be seen named as an algorithm. . . but why? What are we trying to accomplish there?" -Anonymous LA expert

In a similar vein, in response to the idea of "Enhancing writing processes through algorithmic exercises", one LA expert stated:

> "It feels like reskinning LA as computing, and I would be like, Why? We have great terms for this stuff in LA, it's called 'Writing a storyboard', like Why do we need to call it a flow chart, in a lot of LA classes actually already call it a flow chart. Why do we need to call giving feedback to a peer 'abstraction', 'iteration'?" -LA.8

In framing bringing CT-aligned practices and language into literacy classrooms as "reskinning", she points to concerns that CT integration could lead to semantic shifts rather than substantive pedagogical changes and interdisciplinarity. Later in the conversation she noted that some of these approaches might be a starting point for teachers around integrating CT, but highlighted risks, stating that "a lot of teachers might treat it as an endpoint", implying that there were more substantive opportunities for interdisciplinary learning that might be foreclosed.

Another expert expressed a similar sentiment, and highlighted an additional risk: retrenching existing approaches present in Language Arts classrooms that students do not find engaging:

> "I like thinking about how we could bring CT into the ELA classroom and re-imagine that classroom. I think some of these activities [. . .] feel a little like. . .how can we use CT to produce the same kinds of writing, thinking, doing that we've always done in ELA, and that frankly, is sometimes not that engaging". -LA.9

Her comment points not only to the missed opportunities of advancing to more novel forms of pedagogy that she saw as possible through bringing CT practices into Language Arts ("bring CT into ELA [. . .] and reimagine that classroom"), but to the potential that certain kinds of practices that are in epistemic alignment with CT are themselves already aspects of language arts pedagogy that might not be ideal to reinforce and reproduce.

4.6. Possible resolutions to epistemic tensions

While not raised in as consistent and patterned a way as the epistemic tensions shared above, experts in the focus groups also voiced directions through which these tensions might be resolved or otherwise navigated. Specifically, three themes were present related to the resolution of epistemic tensions: (1) grounding CT within the disciplinary epistemology, (2) critically engaging students in understanding the limits of CT in the discipline, and (3) embracing epistemic pluralism.

4.6.1. Grounding CT within the disciplinary epistemology

Where some experts saw the potential for CT to sideline existing disciplinary epistemologies through epistemic chauvinism, some also suggested that this dynamic might be intentionally inverted, with CT being considered and utilized in ways that are actively in service of a discipline's core epistemic values. Above in Section 4.3, we shared how an arts expert expressed support for using patterns in quilting because it privileged an arts epistemology valuing culture and heritage. Similar to that, a social studies expert reflected on how, in his view, CT practices should be situated in ways that directly helped students engage in civic decision making. Here, he discussed an example of how data visualization could be used as a tool to inform students' discussions about how resources should be allocated in their school district:

> "I think [the] example of looking at [school district data] and coming up with some data visualizations to make decisions about where resources should flow, for example. That's great.[. . .] Really, that's what we're all about, is preparing people when they leave the classroom to go out and make productive decisions for themselves, their community, their country, and their world, and if this is really what we're about is trying to get computational thinking at the center of that process, then great". -SS.4

For him, an appropriate relationship in a social studies context, epistemically speaking, would be for the CT practice of data visualization to directly support disciplinary values of preparation to engage in community-based decision making. Implicit in his example is an intentional process on the part of educators to engage in epistemic reflection; actively considering the core epistemic values and goals of their discipline and then how certain epistemic practices of CT advance them. Such a process of ensuring that a learning design actively foregrounds the epistemic values of a core discipline and grounds CT within them could help to avoid epistemic chauvinism, or to actively refrain from employing certain approaches to CT integration in ways that might lead to procedural or contextual reductionism.

4.6.2. Critically engaging students in understanding the limits of CT in the discipline

While concerns about contextual and procedural reductionism came up across all three disciplines, experts also saw opportunities to address these tensions by actively engaging their students in analyzing where CT falls short from the perspectives of their disciplinary epistemology. In discussing concerns around contextual reductionism one social studies expert offered the possibility of having students reflect on the limits of over-generalization and the dangers of characterizing history in overly broad strokes:

> "The first place that really struck me and started to take over my thinking was where it was identifying patterns and then applying them to other parts in history, like a military strategy … For students to come away thinking that a strategy or approach or a pattern is applicable throughout time and in different contexts is dangerous because if history is usable, right, then they have to recognize that we can look for patterns that we might be seeing over time, but we also have to take into consideration how context changes, the way that those apply and what the outcomes are". -SS.2

This expert tries to address the danger of promoting an epistemic misconception from the perspective of a historian – that history is about finding patterns that hold regardless of context – with the potential to teach students the nuance of considering how differences in context limit our ability to directly compare time periods or predict the future. It is possible to infer and extrapolate from her suggestion a pedagogical scenario in which the CT practice of identifying patterns becomes an object of inquiry for students, involving students in reflection on how certain epistemic practices, in this case, pattern recognition, have limitations.

4.6.3. Embracing epistemological pluralism

Although experts saw the potential for epistemic tensions between CT and their disciplinary epistemologies, some expressed an orientation to interdisciplinary learning that celebrated difference, and elevated possibilities for pluralistic epistemic engagement in complex problems. In this expression, they echoed similar sentiments as Turkle and Papert (1990, 1991) in their advocacy of epistemological pluralism, a valuing and recognition of how different epistemic approaches can make unique contributions towards understanding broader phenomenon. One arts expert envisioned scenarios where CT and arts epistemologies worked in ways that actively leveraged the strengths of both:

> "I think that there's a little more substance and realness to how computational thinking and the arts could be married together, and I think about my own children… And my 14-year-old, his world is based on logic and order, and my 10-year-old her world is based on magic and imagination, and I just keep telling them, 'if you guys could get together and start your business would be a really magical combination', because… it seems like there's a real lack of imagination in computer science, and there's a real lack of order and structure sometimes in the arts, and I do think that there's a way for these things to work together to become very powerful". -A.7

In this example, this arts expert acknowledges that arts epistemology may have some limits (i.e. "lack of order and structure") that computational epistemology can attempt to compensate for, and vice versa. By combining the use of different practices from CT and the disciplines, the implication is that this might result in something greater than the sum of its parts. One language arts expert expressed this sentiment when reflecting on an example of having students engage in literacy analysis contrasting digital stories created by different creative computational tools:

> "Love the idea of using these tools to create digital stories, and then comparing and contrasting how the stories are told differently when you use different tools. I feel like there was a lot of connections to some of the points I was making in our previous breakout about how… It's both sides, it's both like how you can apply critical thinking skills from language arts to technology, and then on the other hand, how to use technology to support

> language arts critical thinking and creation, so I like how both of those, how they're really feeding into each other". -LA.8

In this example, the expert sees CT and language arts each bringing something distinct to the table from an epistemic perspective, and expresses enthusiasm around the possibility of productive differences resulting in mutual benefit wherein these disciplines and practices "feed into each other".

5. Discussion

Our analysis shows that experts actively saw the potential for epistemic tensions to emerge when Computational Thinking practices come into contact with humanities and arts epistemologies in interdisciplinary learning environments. More than any specific tension in and of itself, the findings demonstrate that the dynamics implicit in integrating computational thinking into K12 humanities and arts pedagogies are not limited to implementation challenges such as availability of instructional time, technology, curriculum, or teacher capacity, but rather also operate on the fundamental level of epistemic commitments, identities, cultures, and histories of the disciplines in question. Where much of the K12 research on interdisciplinary learning with CT has focused on addressing institutional barriers to implementation through designing integration frameworks (e.g. Barr & Stephenson, 2011), developing instructional materials (e.g. Guzdial & Shreiner, 2021), building teacher capacity (e.g. Coenraad et al., 2022), or understanding institutional dynamics (e.g. Santo et al., 2023), the study presented here affirms that the epistemic dimensions of disciplines are central considerations vis-à-vis contact with one another in pedagogical settings.

The experts we consulted observed tensions that can be seen as operating at different levels of analysis, with different underlying mechanisms, and stemming from distinct sources, including (1) differences between valued epistemic practices, (2) cultural, political, and structural power dynamics that mediate epistemic contexts, and (3) institutional change dynamics within educational settings. This observation in turn suggests to us that possibilities for addressing these tensions must be attendant to these distinctions in character. That is, the nature of the tension and its underlying roots should inform and shape how it might be navigated or mitigated. We first consider these distinctions in the character of the tensions identified, and then how these distinctions might inform attempts to navigate them.

5.1. Tensions stemming from differences between valued epistemic practices

The first two tensions discussed – contextual reductionism and procedural reductionism – we interpret as arising due to potential conflicts between epistemic practices, in and of themselves, that are valued differently by CT versus humanities and arts. That is, these two tensions might be seen as stemming from assumptions on the part of these disciplines about what valued knowledge practices look like. This differences expressed by experts echo broader scholarship outlining key epistemic distinctions between the sciences and the humanities and arts. Foley (2019), for example, articulates four core differences in epistemology of sciences and humanities in terms of valued epistemic standpoints relating to generalizability vs locality, objectivity vs subjectivity, descriptive vs prescriptive claims, and collective knowledge vs individual insight, respectively. Within educational scholarship, Bevan et al. (2019) note differences between arts and STEM epistemic practices in terms of their approaches to inquiry, critique, creativity, sense-making, interpretation, and ethical deliberation, in that case focusing on productive synergy between the two in educational settings.

We see the tension of contextual reductionism relating more specifically to differences in epistemic practices linked to interpretation and analysis, and procedural reductionism relating to differences in those linked to knowledge creation, expression, and production. These tensions echo sentiments noted earlier (Section 2.2.2) expressed by architecture students in the post-secondary, pre-professional settings that Turkle (2009) investigated, who found computational modeling as cutting against existing artistic practices and modalities.

5.2. Tensions stemming from cultural, political, and structural power dynamics that mediate epistemic contexts

The third and fourth tensions discussed – epistemic chauvinism and threats to epistemic identities – can be understood as stemming from cultural, political, and structural power dynamics in which the epistemologies of CT as well as humanities and arts disciplines are situated.

The character of epistemic chauvinism as a tension in particular is resonant of similar challenges related to interdisciplinary power dynamics and dominant styles of reasoning that are well established in scholarship. Salmela & Mäki (2017) contrast the multiple forms that expansionist scientific imperialism can take in interdisciplinary contexts. Imperialism of scope occurs when one discipline's purview creeps widely into the "territory" of another discipline, laying claims to the kinds of phenomenon and problems another discipline historically has worked to explain and solve. Imperialism of style goes a step further, when a discipline attempts to transform the practices and principles of another discipline. And imperialism of standing reaches further still, when a discipline challenges the status of another discipline and works to appropriate the academic resources of the other discipline.

In the context of CT, Section 2.2.2 pointed to instances of imperialism of scope inasmuch as CT claims practices common to other disciplines such as building models and debugging problems are exclusively in the purview of CT. Likewise, Section 2.2.2 pointed to an occurrence of imperialism of style when Denning's (2009) colleague in a different discipline vividly exclaimed "Now you want us to think like you!" This same concern about style is at play in this study's findings when an arts educator worries that CT will reshape the priorities of art away from its roots as an expression of cultural heritage to a focus on the tools used to make art such as algorithmic processes.

Concerns around imperialism of standing were voiced by multiple Delphi experts in examples in which the epistemology of their discipline of language arts, social studies, and arts is being devalued by a consequential actor (such as a University president and a national funding organization), and held to a lower status than STEM and Computer Science disciplines, with implications for funding and resource allocation.

This example of imperialism of standing reflects cultural, political, and structural forces that dynamically shape how disciplines with more quantitative and technical methodologies, such as the natural sciences, economics, are attributed higher prestige by policy-makers and politicians than disciplines with more qualitative and experiential methodologies. This holds true even in contexts of interdisciplinary collaborations where the practical real-world problems not only have measurable dimensions but also social ones (Salmela & Mäki, 2017) and it holds consequences for social scientists that feel the pressure to perform more positivist epistemologies during interdisciplinary collaborations (Albert et al., 2015; Petts et al., 2008). That computational thinking is given high prestige by policy-makers may not be surprising given that public policy, as practiced in the United States educational reform, is centered in practices that either draw on or have strong similarities to computational thinking such as systems thinking and abstract models that reflect what Mike Rose (2009) calls a "technocratic managerial ideology".

The character of threats to epistemic identities as a tension operates in territory that should be well known to those in the computing education space, in that it implicates recognizable dynamics related to identity and safety often considered by research and practice focused on broadening participation (e.g. Rankin et al., 2021). Its possibility, as voiced by experts in the study, invites consideration on how to ensure spaces associated with disciplinary (and in this case, interdisciplinary) learning do not inadvertently alienate learners and actively promote a sense of belonging and ownership.

5.3. Tension stemming from institutional change dynamics within educational settings

The final tension identified, epistemic convergence, can be linked most directly to dynamics that are distinct to educational institutions, wherein broader institutional pressures often incentivize teachers to engage in superficial shifts to existing practice in order to satisfy accountability mandates or otherwise driven by lack of planning time and resources. Such challenges of superficial instructional shifts are well established in policy implementation literature (Coburn et al., 2016), though epistemic similarity acting as a mechanism that might enable it does seem unique.

Epistemic convergence and similarity, in the context of institutional constraints, can be especially problematic when curriculum emphasizes the overlaps between epistemic practices (such as models in science and models in engineering), conflating their particular differences and unique meanings on the one hand, and simply excluding from the curriculum all epistemic practices that do not overlap on the other hand (Reynante et al., 2020). Despite the best intentions to achieve interdisciplinary curriculum in classrooms, the status quo of the "doing school framework" (passive learning rather than original knowledge production) often reinscribes itself, emptying the interdisciplinary activities of their epistemic depth (Schellinger et al., 2022).

5.4. How the character of tensions might inform attempts at mitigation and resolution

We consider the observations shared in this discussion regarding the levels of analysis on which different tensions operate and the underlying mechanisms at play as potentially useful to inform how they might be navigated in practice, and by whom. The three suggestions regarding navigating epistemic tensions voiced by experts (see section 4.6) might each be applicable to address different tensions. For instance, teachers and curriculum designers might, during the instructional design process, heed the suggestion to ground CT in existing disciplinary epistemologies in order to avoid inappropriately engaging in contextual or procedural reductionism. They might shy away from engaging in "semantic shifts" associated with epistemic convergence by aspiring to learning designs that embody epistemological pluralism, as suggested by the experts. Finally, the suggestion that CT-integrated interdisciplinary learning should actively explore the limits of CT within a given discipline might be seen as an effective counter to potentials of epistemic chauvinism.

However, given that we see the character of some of the tensions identified as driven by broader power dynamics, cultural forces, and institutional logics, focusing centrally on individual behavior on the part of actors like teachers or curriculum designers can have limits. How computing is positioned culturally (driving epistemic chauvinism), how certain disciplinary identities are made to be more vulnerable within learning institutions (driving threats to epistemic identities), and how teacher agency is shaped by dominant logics of education reform (driving the "box checking" and "doing school framework" associated with epistemic convergence and shallow reforms) imply that broader social, cultural, political, and institutional shifts are likely necessary in order to change the underlying dynamics mediating epistemic tensions between CT and existing K12 disciplines.

6. Limitations

In considering the conclusions presented, there are a number of limitations to this study that are important to acknowledge. Centrally, the tensions and potential avenues to resolution identified relied on the perceptions of experts, broadly defined – teachers, administrators, and scholars. This meant that the findings were not validated *in situ* within real world learning environments that aimed to integrate CT, something we see as an important and meaningful next step for scholarship related to this phenomenon. The ability of the experts to identify epistemic tensions and resolutions was also qualified in a number of ways. First, approximately half of the experts that were consulted for the study had to rely on a very short introduction via our capacity building activities to ideas and practices related to computational thinking, which may have limited their overall ability to identify epistemic tensions. Results did show, however, that experts both with and without prior knowledge around CT did identify epistemic tensions (see Appendix C). Second, the experts relied not on a purely abstract idea of what CT could look like as it interacted with their discipline, but rather a particular instantiation in the form of the design principles that were presented to them during the focus groups (see Appendix B). Finally, the nature of the perspectives present in the data was likely mediated in additional ways by participants' own, personal, epistemic assumptions and stances. While potentially consequential, these stances went beyond the scope of what was possible to take into account in this manuscript's analysis.

7. Conclusion

This study puts contemporary trends around interdisciplinary integration as a key site of K12 computing education (Lee et al., 2020; Neumann & Dion, 2021; Weintrop et al., 2016) into conversation with the voices and perspectives of experts within disciplines that might be sites of integration. It is critical to actively attend to these perspectives as the broader field of computing education considers further work that brings its ways of knowing and doing into these spaces. Indeed, the finding related to concerns of epistemic chauvinism on the part of computing disciplines warrants the importance of being in active cross-disciplinary dialogue.

We see the expert perspectives surfaced here as advancing broader scholarship on both interdisciplinary learning and integrated computing education pedagogies. Especially given possible risks, consulting experts and exploring tensions that can arise during contact between disciplines provides important starting points for both future scholarship and intentional design of impactful interdisciplinary learning in a way that avoids direct harms. The findings presented in this manuscript are applicable to both practitioners and scholars moving forward. Critically, future research should look to directly study in situ learning environments where CT is integrated into humanities and arts classrooms in order to understand how the possible tensions outlined in this study play out in context. For learning designers including teachers and curriculum developers, the possibilities of harm associated with the tensions that well-informed experts expressed can be seen as an invitation to reflect on whether and how learning designs under development may index such tensions, and how they might avoid doing so in order to advance substantive, equitable, and impactful interdisciplinary learning.

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Appendices

Appendix A: Capacity Building Session Overview

Activity	Description
Introduction: What is computational thinking? (10 minutes)	We first described CT as "formulating problems in a way that enables us to use a computer and other tools to help solve them" (ISTE and CSTA, 2011).
What are Algorithms? (20 minutes)	In this activity, participants wrote directions for making a paper airplane and then discussed how they engaged in the CT practice of algorithm design during the activity. The participants then went through a self-paced CT module to explore algorithms in-depth that also included using Scratch software to code a sprite. They also reflected on how algorithms are currently or could be used to support disciplinary learning in their subject areas. The facilitators included time to field clarifying questions from participants.
What is Abstraction? (20 minutes)	In this activity, we first presented abstraction as "isolating key details while ignoring the remaining elements". Participants were then given an opportunity to work through an online self-paced module that included unplugged and plugged activities that elaborated how we use abstraction in our daily lives. Specifically, the unplugged activity focused on how we used subway maps to navigate public transit and the plugged activity used NetLogo traffic simulation and how it can be used to understand real world traffic patterns. They also reflected on how abstraction is currently or could be used to support disciplinary learning in their subject areas. The facilitators included time to field clarifying questions from participants.
What are Patterns and Data? (20 minutes)	In this activity, the participants watched Beauty of Data Visualization TED talk to better understand how data is all around us and impacts our lives. In small groups they discussed what tensions they saw related to data in our society and how patterns and data could be used in the context of their subject area. The facilitators included time to field clarifying questions from participants.
Q&A & Closing (20 minutes)	Facilitators fielded overall clarifying questions about computational thinking from participants, and went over details around what to expect and logistics related to next steps for participation in the study.

Appendix B: Design Principles for Integrating Computational Thinking in Social Studies, Arts, and Language Arts

	Social Studies CT Integration Design Principles	CT Practices
1	Identify and contextualize core concepts related to social, historical, or political phenomena by filtering out unnecessary details and reducing complexity.	Abstraction
2	Utilize an algorithm (computational or not) to **represent** social, historical, or political phenomena that are an existing subject of study.	Algorithms Abstraction
3	Utilize data visualizations to explore social, historical, or political phenomena	Patterns and Data Abstraction
4	Assess the validity, comparability, and applicability of **data sets** related to social, historical, or political phenomena in order to determine what questions the data set may or may not be able to answer	Patterns and Data
5	Assess the validity, comparability, and applicability of **models** (e.g. visualizations, representations, simulations, conceptual models) related to social, historical, or political phenomena in order to determine what questions they may or may not be able to answer or biases present in these representations.	Abstraction
6	Analyze patterns and data to generate new questions and/or make predictions about social, historical, or political phenomena	Patterns and Data
7	Analyze algorithms that are representations of social/historical/political phenomenon	Algorithms
8	Analyze social/historical/political phenomena through developing an algorithm (flow chart of steps/criteria/etc). This process includes identifying, sorting, and categorizing social/historical/political phenomena.	Algorithms Abstraction

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	Social Studies CT Integration Design Principles	CT Practices
9	Analyze algorithms embedded in social phenomena (“seeing algorithms in society”) in order to see their social, historical, or political implications	Algorithms
10	Analyze and explore how maps, as a form of abstraction, represent and embed categorical distinctions within the context of political/geo-political processes.	Abstraction
11	Identify patterns or rules in order to generalize and/or transfer the a solution/model to similar situations	Patterns and Data Abstraction
12	**Model** social, historical, or political phenomena through computational or non-computational means to reduce complexities and highlight relationships.	Patterns & Data Algorithms Abstraction
13	Create an algorithm of proposed social policy/practice (“proposing new societal configurations of algorithms”)	Algorithms
14	Create data representations in order to understand the use and implications of abstraction within social, political, or historical phenomenon	Patterns & Data Abstraction

	Arts CT Integration Design Principles	CT Practices
1	Explore artistic works by highlighting the underlying rules and constraints artists intentionally used to create them.	Algorithms
2	Use computational concepts/tools to illustrate art concepts/process	Algorithms
3	Use decomposition to breakdown artistic processes and individual pieces of artwork	Algorithms Abstraction
4	Use computing to create interactive art	Algorithms
5	Create artistic works that incorporate sensory effects (e.g. movement, light, or audio) through use of physical computing	Algorithms
6	Create artistic works (computational or non-computational) using algorithmic processes or tools	Algorithms Patterns
7	Create and utilize categories to analyze similarities and differences in artistic works	Abstraction Patterns & Data
8	Use computational concepts to curate and present artistic works	Algorithms
9	Analyze social, historical, political, and economic influences on visual art through developing an algorithm (flow chart of steps/criteria/etc) or by analyzing the similarities and differences between various art work.	Abstraction Patterns & Data
10	Analyze visualizations to understand how aesthetics are used to communicate meaning	Patterns & Data Abstraction
11	Use principles of art to represent and communicate data through computational or non-computational means	Patterns & Data Abstraction
12	Create artistics works that incorporate data	Patterns & Data
13	Represent analyses of artistic works through data	Patterns & Data

Language Arts CT Integration Design Principles		CT Practice(s)
Design Principles – Distant Reading through computational thinking analysis		
1	Analyze literary elements in text through algorithmic exercises.	
1.1	Identify and analyze literary elements in text by using flowcharts, storyboards, or other representational forms, citing evidence from text when making selections.	Algorithms Patterns
1.2	Identify, analyze, and critique authorial moves by following an algorithm.	Algorithms Patterns
2	Examine specific excerpts in text by annotating and abstracting elements from text.	
2.1	Expand understanding of literary elements of text by tracing usage and interactions of specific words or ideas in quantitative literary data and visualizations.	Abstraction Pattern & Data
2.2	Expand understanding of text by creating complementary visuals (tables, charts. graphs etc.) from text analysis data (i.e. word frequencies, syllable counts, meter).	Abstraction Pattern & Data
2.3	Support close reading of a text by uploading texts to analysis applications to organize quantitative literary data and use data visualizations to identify new patterns in the text for close reading.	Abstraction Pattern & Data
3	Examine a text through patterns and quantitative literary data.	
3.1	Re-read and analyze text more closely by using quantitative literary data and visualizations to identify parts of text (phrases, word choices) that shape meaning or tone.	Patterns & Data Abstraction
3.2	Pose questions about how larger portions of the text relate to each other by analyzing quantitative literary data (e.g. frequently used words per paragraph, chapter).	Patterns & Data
3.3	Identify patterns and pose questions about how two or more texts relate to each by using quantitative literary data.	Pattern & Data
Design Principles – Enhancing Writing Processes through Computational Practices		
4	Enhance writing process, in self and peer texts, through algorithmic exercises	
4.1	Prepare to write narrative texts by creating flowcharts, storyboards, or other representational forms.	Abstraction Algorithms
4.2	Support processes of iteration and feedback through identifying writing conventions in self or peer writing through creating abstractions, such as storyboards.	Abstraction
4.3	Support processes of iteration and feedback through identifying writing conventions in self or peer writing through creating and using algorithms, such as tables.	Algorithms
5	Enhance the writing process by abstracting writing conventions from text.	
5.1	Reverse engineer writing patterns from a sample text by identifying patterns.	Abstraction Algorithms Patterns & Data
5.2	Reflect on how reverse engineering writing signature qualities from a sample text enabled and encumbered writing.	Abstraction
5.3	Decompose and reason about entire texts as specific syntactic structures (intro, development, conclusion; topic sentence, supporting sentence, concluding sentence) to determine writing patterns.	Abstraction Algorithms
Design Principles – Composing Computationally Enhanced Texts		
6	Write a response using quantitative and qualitative literary data.	
6.1	Compose a mixed literary analysis that presents quantitative and qualitative literary data to support an an interpretation of a text.	Pattern & Data Abstraction
6.2	Compose expository writing that presents quantitative data to impart information on a given topic or fact.	Pattern & Data Abstraction
7	Create interactive composition through a computer algorithm.	
7.1	Create a descriptive composition that utilizes a computational tool	Algorithms
7.2	Create a narrative composition that utilizes a computational tool.	Algorithms
7.3	Create an expository composition that utilizes a computational tool.	Algorithms
7.4		Algorithms

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Language Arts CT Integration Design Principles		CT Practice(s)
	Compare computational tools and discuss their affordances and limitations when it comes to different forms of composition (i.e. argumentative, descriptive, narrative, expository).	
Design Principles – Critical analysis of computational texts and practices		
8	Assess the affordances and limitations of computational practices in terms of analyzing texts and communicating evidence. ("should we even be using CT in ELA")	Patterns & Data Abstraction
9	Assess authorial intent, motive, and impact of computational tools or platforms ("tools as texts").	Algorithms
9.1	Analyze computational tools or platforms as texts by posing questions.	Algorithms
9.2	Analyze how authorial intent and motive shape the design of computational tools or platforms.	Abstraction
9.3	Analyze affordances and limitations of computational tools or platforms.	Abstraction
10	Understand the relationship between communication culture and computational culture.	Abstraction

Appendix C: Epistemic Tensions Code Frequency

Participant	Prior CT experience	Contextual reductionism	Procedural reductionism	Epistemic chauvinism	Threats to epistemic identities	Epistemic convergence
LA.1	No	x		x		
LA.2	Yes	x				
LA.3	Yes	x	x			
LA.4	Yes	x	x	x		
LA.5	No	x		x		x
LA.6	Yes		x	x		
LA.7	No		x			x
LA.8	Yes					x
LA.9	No					x
LA.10	Yes					
LA.11	Yes					
LA.12	Yes					
LA.13	Yes					
LA.14	No					
LA.15	No					
LA.16	No					
SS.1	No	x	x			
SS.2	Yes	x				
SS.3	No	x				
SS.4	No			x		x
SS.5	Yes					x
SS.6	Yes					
SS.7	Yes					
SS.8	No					
SS.9	No					
SS.10	No					
SS.11	No					
SS.12	No					
SS.13	No					

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Participant	Prior CT experience	Contextual reductionism	Procedural reductionism	Epistemic chauvinism	Threats to epistemic identities	Epistemic convergence
SS.14	No					
A.1	Yes	x				
A.2	No	x	x			
A.3	Yes		x	x	x	
A.4	Yes		x	x	x	
A.5	No		x			x
A.6	Yes			x		
A.7	No			x		x
A.8	Yes			x		
A.9	Yes			x		
A.10	No			x		
A.11	Yes					
A.12	Yes					
A.13	No					