Maintaining pluralism when embedding computational thinking in required science and engineering classes with young adolescents

Article *in* Computer Science Education · June 2021

DOI: 10.1080/08993408.2021.1940787

2 authors:

David W. Jackson
Boston College, USA

Yihong Cheng
Boston College, USA

COMPUTER SCIENCE EDUCATION
https://doi.org/10.1080/08993408.2021.1940787

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Maintaining pluralism when embedding computational thinking in required science and engineering classes with young adolescents

David W. Jackson and Yihong Cheng

Lynch School of Education and Human Development, Boston College, Chestnut Hill, MA, USA

ABSTRACT

Background and Context: Computational thinking and practices (CT|P) are key competencies for learners in science and engineering. For studies with young adolescents as participants, manifested research philosophies are sometimes inconsistent with societal pluralisms.

Objective: Based on research literature from 2016 to early 2019 for CT|P in required science and engineering classes with youth ages 10-15 – a sensitive age range for cognitive and affective development – we wrote a literature review that argues for the use of more pluralistic and critical research philosophies, which will strengthen research design, implementation, and meta-inferences (Collins et al., 2012).

Method: We analyzed 20 qualifying studies per research philosophies common to mixed research, giving extra attention to studies that acknowledge cultural pluralisms, engage those pluralisms in conversation with each other, and ensure that historically marginalized populations have equitable – not just equal – participation (Onwuegbuzie & Frels, 2013).

Findings: We found that studies consistently emphasized *pragmatism-of-the-middle* and *communities of practice;* sometimes operated within *critical realist, pragmatism-of-the-right*, or *transformative-emancipatory* philosophies; and rarely engaged in *dialectical* ways.

Implications: To avoid decontextualized or overly individualistic approaches that fail to address systemic and institutional social inequities (in education, housing, healthcare, policing, voting, etc.), future work should take more pluralistic and critical philosophical approaches. We highlight several exemplars in hope that research will support youth in maintaining and extending computational practices in culturally sustaining ways (Paris, 2012).

ARTICLE HISTORY
Received 17 November 2020
Accepted 8 June 2021

KEYWORDS
Computational thinking; computational practices; science and engineering education; critical dialectical pluralism; philosophy of research; adolescence

1. Introduction

1.1 Rationale

A pluralistic society needs both the many and one to be vibrant. (Paris, 2012, p. 95)

A culturally pluralistic society with democratic educational institutions cannot "exist and thrive" without a combination of "within-group cultural practices" and "common,

CONTACT David W. Jackson david.jackson@bc.edu 140 Commonwealth Avenue, Campion Hall, Room 119A, Chestnut Hill, MA 02467, USA

across-group cultural practices” (Paris, 2012, p. 95). Unfortunately, educational and cultural practices that value both "the many and one” have, to take the history of the US as one example, been supported "in word – though rarely in deed – when immigrant communities and communities of color are involved” (p. 95). Students nowadays still face harsh challenges to maintain their cultural heritage, as the stances of cultural relevance or responsiveness do not necessarily offer details for supporting students' *repertoires of practice* (Gutiérrez & Rogoff, 2003). In addition to pluralities of culture and immigrant status, inequities related to race/ethnicity, socioeconomic status, gender, and/or additional identity markers exist intersectionally through systemic and institutional mechanisms like governmental funding, organizational recruitment and mentoring, physical environments of schools, and more (Blikstein, 2018; Cho et al., 2013; S. L. Rodriguez & Lehman, 2017). We therefore wrote this literature review to support researchers and educational practitioners in developing strategies to design and refine learning environments, which can maintain and sustain students' cultural backgrounds as assets (Paris, 2012).

Specifically, we focused on the integration of computational thinking (CT) into science and engineering education for required science and engineering classes with young adolescents. Ages 10–15 are a particularly sensitive period for cognitive and affective development (Eccles & Roeser, 2011; Santrock, 2007). As a way of thinking, CT covers a range of attitudes and skill-sets that involve "solving problems, designing systems, and understanding human behaviors by drawing on the concepts fundamental to computer science” (J. M. Wing, 2006, p. 33). Previously CT has been narrowly conceptualized as science-heavy and for computer scientists only, yet it has received increasing attention from practitioners, researchers, and policymakers across all disciplines (Lee & Malyn-Smith, 2020; Voogt et al., 2015). For example, the Next Generation Science Standards (NGSS) stress the use of mathematics and computational thinking (NGSS Lead States, 2013). Also, the Common Core State Standards expect that students will "use technological tools to explore and deepen their understanding of concepts” (National Governors Association, 2010, p. 7).

Recent empirical work reflects these trends, as studies hint at CT's potential to help students interested in various disciplines to improve their critical analytical skills (Porter et al., 2014). Also, national organizations have argued that students proficient in CT are more likely to find themselves in a favorable position as they enter the job market, as the number of degrees offered in STEM fields is seeing an upward trend (National Science Foundation, 2010).

1.2 Teaching computational thinking (CT) in the subjects of science, technology, engineering, and mathematics (STEM)

During our literature search (see Table 1), most examples were for adolescents older than 15, children younger than 10, teacher preparation and professional development, or out-of-school-time learning (e.g. Liu et al., 2017; Yadav et al., 2018). In-school-time opportunities for computer science classes can be especially rare for low-income students in insufficiently funded public schools (Blikstein, 2018; S. L. Rodriguez & Lehman, 2017); embedding CT into required STEM classes is one way to increase access to education in computation.

Table 1. Search procedure.

	Google Scholar	ACM Digital Library	IEEE Xplore	ERIC	total
"computational thinking" AND "science classroom"	1080	7	33	13	1133
Date: Since 2016 *(1 January 2016–15 April 2019)*	586	6	22	7	621
Based on titles: eliminated reviews, non-science disciplines, professional development, CV's, books, non-adolescence, policy briefs, teachers-only, introductory matter, programs of studies, and design descriptions	53	4	14	3	74
Based on abstracts and full manuscripts: eliminated one-session interventions; camps; position papers; workshops; non-classroom interventions; science fairs; historical accounts; CT named but not explored (e.g. as part of listed NGSS practices); outreach; citations only; students as consumers (vs. creators); late adolescence (e.g. 11th- and 12th-graders); CT for researchers' internal use (e.g. data storage)	14	2	1	1	18
two-study manuscripts	*+1*	*+1*	*0*	*0*	*+2*
FINAL NUMBER OF STUDIES	15	3	1	1	20

Note. Substituting "science class", "engineering class", and "engineering classroom" for "science classroom" yielded no additional unique results.

Further, there have been insufficient discussions about how CT can be taught in a way that sustains historically underrepresented and marginalized students' cultural heritage and raises their awareness of social justice-centered practices to combat structural and institutional oppression. We therefore attempted to use this literature review to promote the use of culturally sustaining pedagogy (Paris, 2012) and an approach of *critical dialectical pluralism*, which "privileges those paradigms or worldviews that promote and sustain an egalitarian society" (Onwuegbuzie & Frels, 2013, p. 3). To ensure that we examined "prevailing power structures and relationships between the oppressors and the oppressed" (Onwuegbuzie & Frels, 2013, p. 14), we used Bronfenbrenner's (1993) ecological systems of development to analyze studies at various levels of social systems (see Figure 1).

We focused on CT education experienced by young adolescents, as they are at a key stage of their lives that substantially affects how likely they are to pursue STEM careers. For example, in a longitudinal study by Tai et al. (2006), students who reported interest in science in 1988 when they were 8th graders were three times more likely than those who did not, to obtain a science degree within 18 years. Similarly, Havard (1996) found that once students reached the age of 14, it became virtually impossible to remove physics and chemistry from their lists of least popular subjects. Despite the cognitive and affective sensitivity of young adolescence, studies on teaching CT to date in required STEM course-work have predominantly focused on adults, students younger than 10 or older than 15 years of age, or extracurricular classes, clubs, and camps.

Given the gap in the literature for culturally sustaining/responsive teaching CT in required science and engineering classes with young adolescents (Blikstein, 2018; S. L. Rodriguez & Lehman, 2017), we sought to engage with diverse research approaches, looking for common ground that could provide a strong foundation for future work. Based on the scholarly literature from early 2016 through early 2019, we addressed the research questions,

(1) What are some conceptual frameworks that researchers are using?

(2) How do the conceptual frameworks relate to philosophies of research?

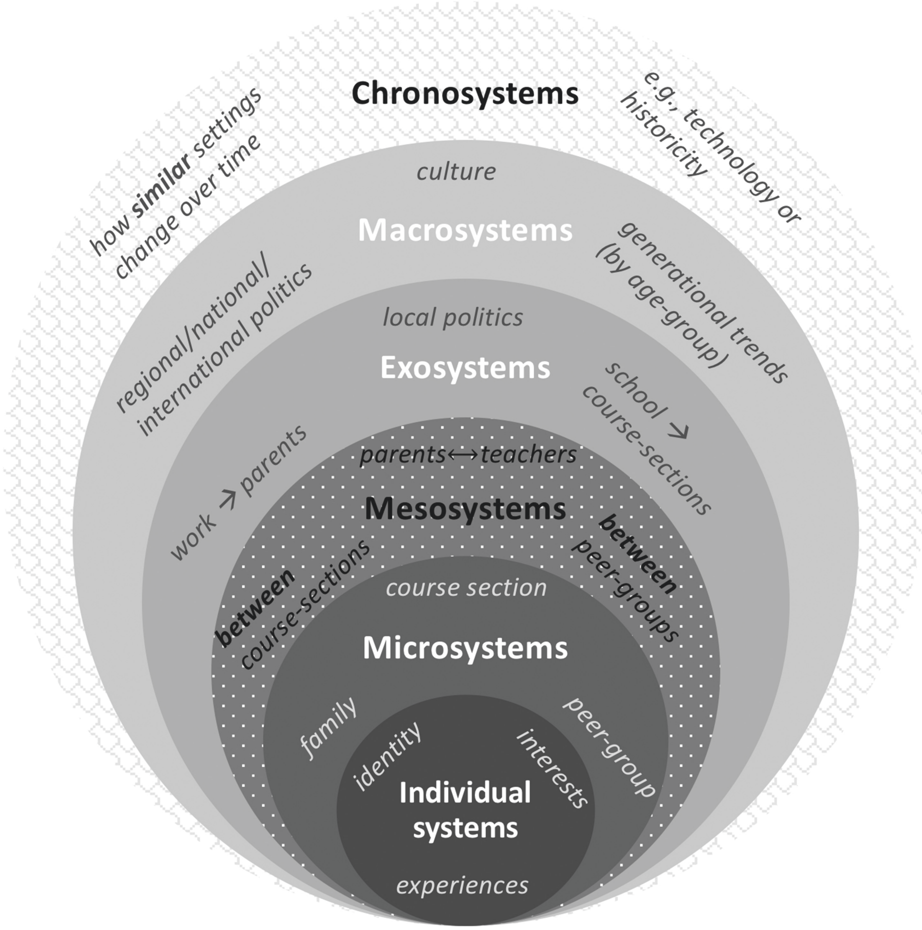

Figure 1. *Levels of* Bronfenbrenner's (1993) *ecological systems of development. Note*. Levels can be intrapersonal (individual systems), *within* small groups (microsystems), *between* small groups (mesosystems), local groups (exosystems), regional/national/international groups (macrosystems), and temporally-based changes within settings (chronosystems).

(3) What are the implications for practice, of using the frameworks and philosophies?

1.3 Conceptual Framework: Culturally Sustaining Pedagogy and Research Philosophies

1.3.1 Culturally Sustaining Pedagogy

Ladson-Billings' framework of Culturally Relevant Pedagogy (CRP), which emphasized empowering students of color to maintain their cultural practices and critically challenge oppressive structures, has been extensively used and misused, the misuses owing in part to terminology (Ladson-Billings, 2014; Paris, 2012). As the aftermath of slavery and colonialism continue to dehumanize students of color in schools, the mission of maintaining students' cultural practices has often failed to sustain students' repertoires of practice (Gutiérrez & Rogoff, 2003). This failure necessitates the use of Culturally

Sustaining Pedagogy (CSP) to "perpetuate and foster – to sustain – linguistic, literate, and cultural pluralism as part of the democratic project of schooling" (Paris, 2012, p. 93).

In the domain of education in CT, CSP is an especially under discussed topic. As Vakil (2018) noted, many computer science education studies have followed rationales that are "commonly linked to the economic needs of technology companies" (p. 27) without addressing the nature of computer science as a discipline that is "profoundly consequential across multiple dimensions of the human experience" (p. 28). Despite J. M. Wing's (2006) work to extend CT beyond computer programming into a way of thinking and skill set for everyone, the current goals of computer science education are often reduced to more efficiently producing productive software developers and pipelining them to job placements (Guzdial, 2015). Meeting an urgent need for a more empowering vision in the computer science education community, CSP was therefore both the conceptual framework we used to analyze existing studies and the desirable goal of computer science education as we conducted our literature review.

1.3.2 Research Philosophies

Most studies used mixed methods, wherein researchers used both qualitative and quantitative methods to arrive at more complete understandings, provided that the methods are aligned to complement each other (Onwuegbuzie & Frels, 2013). As noted by Collins and colleagues (Collins et al., 2012), it is crucial for mixed research to have "philosophical clarity", a *lack* of which

> could reduce [researchers'] abilities to conceptualize their studies in a coherent manner, which, in turn, would reduce their abilities to design their mixed research studies adequately, which, in turn, would negatively affect the implementation of mixed research studies, in general, and the formulation of quality of metainferences, in particular. (p. 858)

For examples of research philosophies, we turned to Onwuegbuzie and Frels (2013), who identified 13 research philosophies, of which we saw strong evidence of six in our literature review, as shown in Figure 2. For logical coherence, our overview of philosophies proceeds, in terms of ontology, roughly from more realism to more pluralism, albeit acknowledging that there are variations within each research philosophy.

Pragmatism-of-the-right is a research philosophy that consists primarily of realism, with a minimal share of pluralism (Putnam, 2002). Despite embracing the possibility of applying multiple methods as tools to investigate external reality, pragmatism-of-the-right holds that truth has to be eventually understood in an objective fashion embedded in human senses for the sake of cognitive security, which limits the choices humans have (Pragmatism and objectivity, 2017).

In comparison, *pragmatism-of-the-middle* is a research philosophy more balanced in terms of realism and pluralism, which routinely mixes seemingly incompatible paradigms to further action and eliminate doubts (Johnson & Onwuegbuzie, 2004). Due to its focus on the result instead of the process, pragmatism-of-the-middle takes the stance that despite ontological and epistemological conflicts, multiple research methods can be mixed to generate "a meaningful engagement with differences" that leads to conceptually and practically valuable understandings (Greene & Hall, 2010, p. 124).

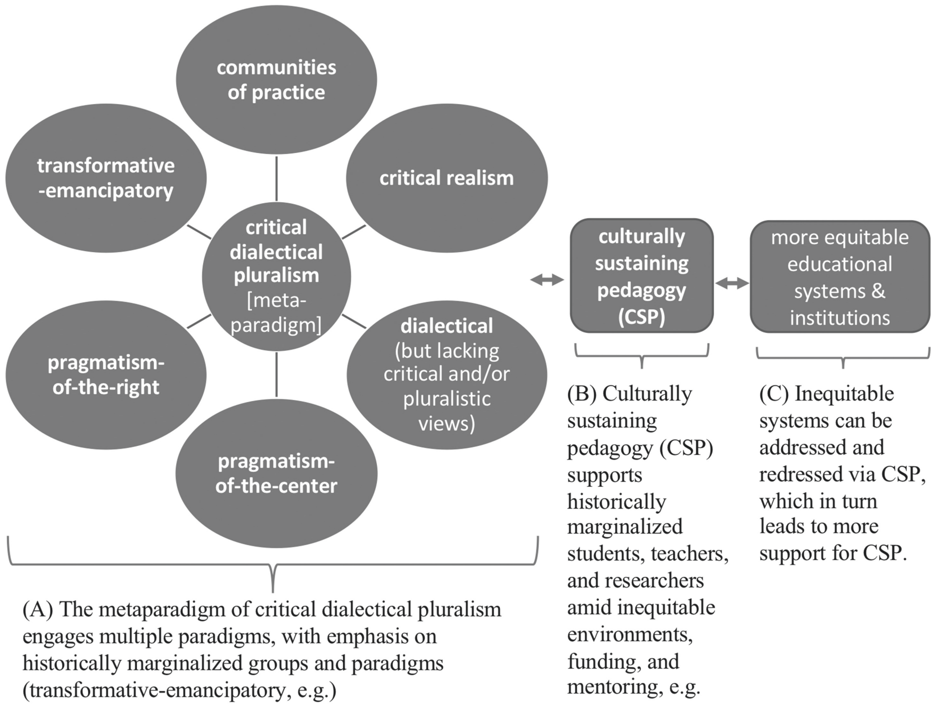

Figure 2. Relationships between research philosophies, pedagogy, and institutional equity. *Note.* (A) Critical dialectical pluralism plays a central role and "serves as a metaparadigm" (Onwuegbuzie & Frels, 2013, p. 16) to engage the various philosophies presented radially. (B) One result of a critical dialectical pluralistic approach is the fostering of culturally sustaining pedagogy (CSP), which (C) in turn promotes more equitable educational systems.

A *communities of practice* approach foregrounds various social levels into the process of resolving methodological disputes. In this approach, methods can be assigned with different priority, depending on how practical and useful they are in terms of addressing the research problem(s) or question(s) (Denscombe, 2008). Assuming that learning happens in a community of learners, communities of practice can also be categorized into several different branches in terms of levels of ecological systems (Bronfenbrenner, 1993), how individuals develop to meet the needs of the larger society (Piaget & Cook, 2013), and how societal resources support individual learners (Vygotsky et al., 1978).

Critical realism takes the stance of epistemological relativism by recognizing that there are multiple equally valid ways to understand reality (Maxwell & Mittapalli, 2010). This stance represents a departure from its philosophical origin of transcendental realism, which accepts knowledge as based in intransitive objects that are independent of human activity (Bhaskar, 1998). Critical realism perceives research designs as "real entities" instead of "models for research", which challenges researchers to consider their presence, relationships with research participants, and interventions as "a real component of the 'design-in-use of a study'" (p. 153). This approach foregrounds researchers' and participants' dispositions and interactions with larger learning environments and communities (Zachariadis et al., 2010).

The *transformative-emancipatory* approach extends research towards social justice-centered inquiries that are "inherently contextual, emotional, and social", which necessitates making decisions "about which goals are meaningful" and "which methods are most appropriate" for historically marginalized populations (Morgan, 2014, p. 1050). Viewing knowledge as constantly influenced by human interests, power, and social relationships, this research philosophy holds that research should be conducted in emancipatory, anti-discriminatory, and participatory ways that critically address the question of "research for what" (Mertens, 2003).

Finally, *dialectical pluralism* is the research philosophy that takes pluralism to perhaps the furthest extent, as it provides a meta-perspective through which researchers explore diverse research philosophies (Johnson, 2017). Dialectical pluralism "recommends that [someone] concurrently and equally value" various philosophies (Johnson, 2017, p. 159). However, as noted by Onwuegbuzie and Frels (2013), it is unclear how dialectical pluralism "helps to give voice to those with the least power" or how a transformative-emancipatory approach will avoid privileging researchers (p. 13). Thus, Onwuegbuzie and Frels (2013) propose a stance of *critical dialectical pluralism*, to ensure that research "goes far enough in terms of [including] people who have been traditionally excluded" (p. 13).

Given the relevance of these six research philosophies to the studies we located for this literature review, as well as to our goal of promoting culturally relevant CT education in formal settings, we have deliberately chosen to incorporate a critical lens in dialectical pluralism. This approach allows us to assess existing studies' potential to promote local communal knowledge and expand it to foster an egalitarian society, so that students of diverse backgrounds can truly maintain and sustain their cultures as they engage in culturally sustaining (Paris, 2012) learning experiences in CT through science and engineering.

2. Methods

2.1 Objectives and Methodology

We aimed to produce a landscape review with shared implications despite the studies' contrasting research approaches. Specifically, we embraced "concepts sharply at odds" in hopes that they might nonetheless "converge with implications for a given range of practice" (Strike & Posner, 1983, p. 354), namely for required science and engineering courses with early adolescent youth. We particularly sought to faithfully represent some of the more transformative/emancipatory and critical-dialectical studies. This orientation towards prioritizing perspectives that have historically been marginalized – rather than seeking equal treatment, which could perpetuate the status quo – is consistent with our overarching approaches of critical dialectical pluralism (Onwuegbuzie & Frels, 2013) and culturally sustaining pedagogy (Paris, 2012). Our search methodology is illustrated in Figure 3.

We chose 2016 as a starting point, given a similar review process with published findings by Lockwood and Mooney (2018). Considering their five research questions, we recognized the extensive literature on the what's and how's of teaching CT, along with recent work on assessing and implementing CT, so we chose to focus on the "why" of teaching CT.

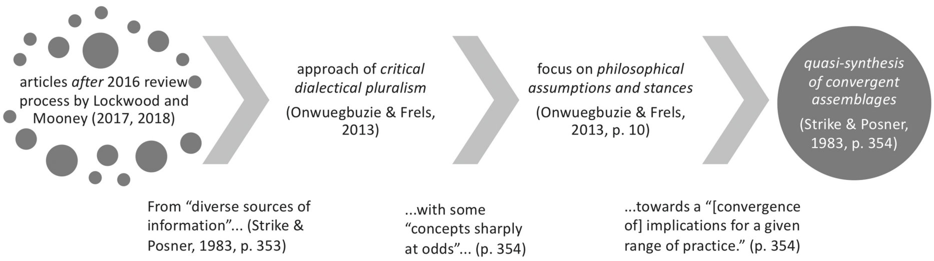

Figure 3. Search methodology. *Note*. As informed by critical dialectical pluralism, and based on diverse sources with a variety of philosophical assumptions and stances, we moved towards shared implications for practice.

This recognition is supported by our independent coding (the first and second author), for the research philosophies described above, as manifested in Lockwood and Mooney (2018.) Specifically, their manuscripts included five major sections per their five research questions, and each of those sections had its own introductory and concluding *sub*section, which was what we coded. Though the second manuscript is a clear evolution of the first, we found the documents different enough to merit independent coding. We used values coding (Saldaña, 2009) to analyze which research philosophies were prioritized in the two manuscripts.

Our coding had 100% inter-rater reliability, finding that the two manuscripts contained elements of pragmatism-of-the-right, pragmatism-of-the-center, and communities of practice. There were opportunities to engage additional paradigms, through more equity-oriented studies involving the homebuilding charity Habitat for Humanity (Pulimood et al., 2016) and an assistive-technology project (Yang et al., 2011). In the spirit of those two studies, this paper includes the more pluralistic values inherent to critical realism, transformative-emancipatory approaches, and dialectical pluralism, thus adding axiological depth along with temporal breadth.

2.2 Process of Data Generation and Analysis

2.2.1 Search Procedure for Data Generation

After searching for "computational practices" alone in March of 2019, we expanded our search to include "computational thinking" that April. Table 1 summarizes how reduced over 1,100 initial results to the final 18 manuscripts with 20 studies. To guard against negative effects of self-selection (Vallett et al., 2018), we chose to review studies for *required* STEM classes. Given our interest in natural sciences, engineering, and computer science, as well as recent initiatives to synergize science and engineering practices (NGSS Lead States, 2013), we elected to delve into teaching computational thinking in science and engineering classes. We chose to focus on young adolescence, operationalized as ages 10–15 (Santrock, 2007), given its sensitivity for identity and interest (Eccles & Roeser, 2011) and long-ranging implications for college and career attainment in science, technology, engineering, and mathematics (Tai et al., 2006).

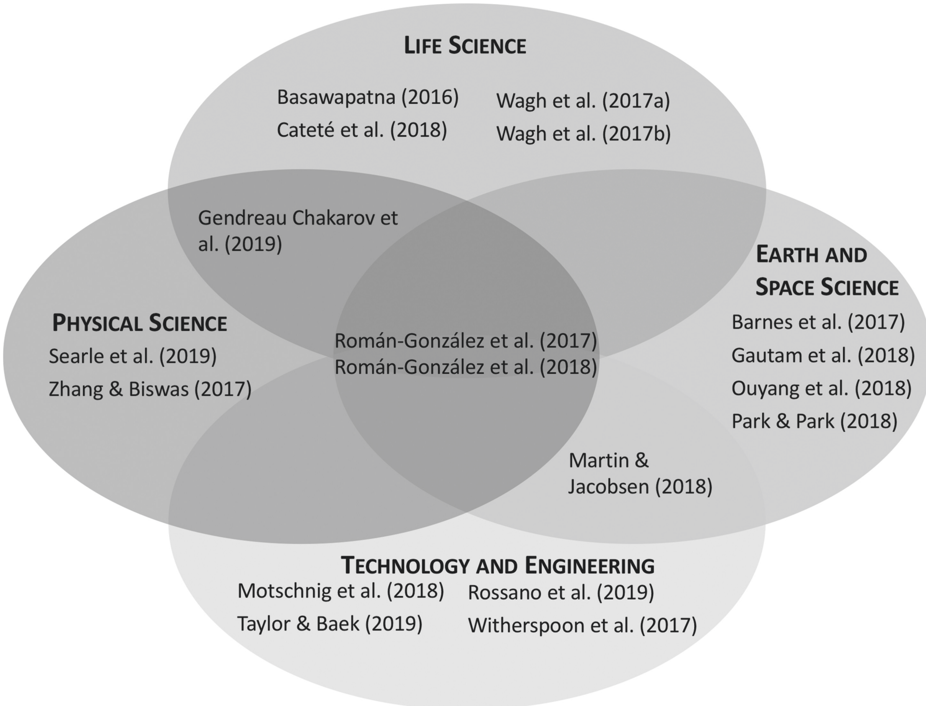

Figure 4.

Ultimately, we found studies spread across four disciplines of science per the Next Generation Science Standards (NGSS Lead States, 2013), as shown in Figure 4. Further, the studies explicitly mentioned a wide variety of frameworks, which we list in Table 2.

2.2.2 Analysis of Included Articles

The two of us (the first and second author) grouped the frameworks from Table 2 into six of the 13 philosophies identified by Onwuegbuzie and Frels (2013), given that the selection of these frameworks reflected the authors' perspectives on the nature of computer science knowledge and how such knowledge can be acquired. We independently coded the frameworks, with an inter-rater reliability of greater than 0.92, above the desired baseline of 0.85–0.90 established by Saldaña (2009). After independently grouping, we discussed differences in coding, ultimately arriving at full agreement. The final groupings are shown in Table 3.

3. Results

We found that studies consistently emphasized *pragmatism-of-the-middle* and *communities of practice*; sometimes operated within *critical realist, pragmatism-of-the-right*, or *transformative-emancipatory* philosophies; and rarely engaged in a *dialectical stance*. For logical coherence, we proceed in the same order as the introduction, from roughly more realist to more pluralistic views.

Table 2. Included publications.

Author(s)	Year	Location(s)	Gr.	Frameworks explicitly mentioned
Barnes et al.	2017	*Massachusetts, USA*	8	Wing (2006); triadic game design [reality-meaning-play]
Basawapatna	2016	*S. Ute Tribe lands & Colorado, USA*	7	Wing (2008); CT Patterns [agent-based]; Consume-Create Spectrum
Cateté et al.	Blikstein, 2018	"two local . . . magnet middle schools"	7 & 8	K12CS (2016); Weintrop et al. (2014); research-practice partnership (RPP); design-based implementation research (DBIR)
Gautam et al.	2017	Nepal	7	Wing (2006); interest; apprehension; deep learning
Gendreau Chakarov et al.	2019*	"large urban public school district"	5–8	NGSS; Weintrop et al. (2016); place-based education; student engagement
Martin & Jacobsen	Blikstein, 2018*	*Alberta, Canada*	6, 8	Computational Concepts, Practices, & Perspectives (CPP; Brennan & Resnick, 2012)
Motschnig et al.	Blikstein, 2018	Austria	2–7	Wing (2006); ACM; IE; Stanford Design Thinking Method for Kids
Ouyang et al.	2018	S. California, USA	4–6	ISTE; Quest CT Coached Lesson Study
Park, Y.-S. & Park, M.	2018	(Republic of) Korea	K-12	Yang et al. (2011); NGSS; Korean Science Curriculum; CT Practice Framework; CT in STEAM Analyzing Tool
Román-González et al.	2015	Spain (unspecified localities)	5–10	Yang et al. (2011); Computational CPP; Cattel-Horn-Carroll (CHC) model of intelligence; Primary Mental Abilities (PMA) battery; RP30 problem-solving test
Román-González et al.	Román-González et 2018	Spain: Valencia area, Madrid, and Sevilla	5–11	Yang et al. (2011); Computational CPP; CHC model of intelligence; PMA battery; Big Five Questionnaire-Children version; self-efficacy
Rossano et al.	Román-González et al., 2018	Terlizzi, Italy	6–7	Wing (2006); constructionism
Searle et al.	2019	western US + non-contiguous US	8	Computational CPP; constructionism; culturally responsive schooling
Taylor & Baek	2019	suburban Idaho, USA	4–5	CT Test (CTt; Román-González, 2015); "thinking hat roles" (De Bono, 2016)
Wagh, Levy, et al.	Román-González et al., 2017	midwest USA	7	Wing (2006); Weintrop et al. (2016); "code first" modeling environments
Wagh, Cook-Whitt, et al.	2017	midwest USA	10	constructionism; tinkering with code; computational engagement; (science) conceptual engagement
Witherspoon et al.	2017	Pennsylvania, USA	6	constructivism; Wing (2006); NGSS; low-road and high-road transfer (Salomon & Perkins, 1989)
Zhang & Biswas	Gautam et al., 2017	USA	8	Knowledge, Skills, and Abilities specific to CT using Simulation and Modeling (KSAs in CTSiM); evidence-centered design

Note. * = papers with two applicable studies; *italics = inferred from curriculum or grant information.*

Table 3. Key frameworks from included publications, as grouped by research philosophies.

Philosophy	Frameworks
Pragmatism-of-the-right	Big Five Questionnaire-Children version, Cattell-Horn-Carroll (CHC) model of intelligence; CT in STEAM Analyzing Tool; CT Patterns [agent-based]; CT Practice Framework; CT Test (CTt; Román-González, 2015); evidence-centered design; Knowledge, Skills, and Abilities specific to CT using Simulation and Modeling (KSAs in CTSiM); Next Generation Science Standards (NGSS Lead States, 2013); Primary Mental Abilities (PMA) battery; RP30 problem-solving test; self-efficacy; transfer, "low-road" and "high-road" (Salomon & Perkins, 1989); Wing (2006), Wing (2008)
Pragmatism-of-the-middle	Computational Concepts, Practices, & Perspectives (CPP; Brennan & Resnick, 2012); Computer Science Teachers Association (Yang et al., 2011); Consume-Create Spectrum; design-based implementation research (DBIR); Informatics Europe & ACM Europe (2013); International Society for Technology in Education (ISTE; 2016); K-12 Computer Science Framework (K12CS; 2016); Korean Science Curriculum (2015 version); Quest CT Coached Lesson Study; research-practice partnership (RPP); Stanford Design Thinking Method for Kids; "thinking hat" roles (De Bono, 2016); triadic game design [reality-meaning-play]
Communities of Practice: Individual- to micro-level focus	"code first" modeling environments; CPP (Brennan & Resnick, 2012); computational engagement; Yang et al. (2011); conceptual engagement (in natural sciences); constructionism; constructivism, more individual (e.g. Piaget & Cook, 2013); culturally responsive schooling/education*; deep learning; Informatics Europe & ACM Europe (2013); interpretivism, *more individual*; K12CS (2016); Korean Science Curriculum (2015 version); NGSS Lead States (2013); phenomenology; self-efficacy; Stanford Design Thinking Method for Kids; tinkering with code; Weintrop et al. (2014), Weintrop et al. (2016); Wing (2006), Wing (2008)
Communities of Practice: Macro- *or* meso- to individual-level focus	constructivism, *more social* (e.g. Vygotsky et al., 1978; Gutiérrez & Rogoff, 2003; Lave & Wenger, 1991); design-based implementation research (DBIR); International Society for Technology in Education (ISTE; 2016); interpretivism, *more social*; place-based education; Quest CT Coached Lesson Study; research-practice partnership (RPP)
Critical Realism	apprehension, interest; phenomenology; student engagement (affective, behavioral, cognitive)
Transformative-Emancipatory	culturally responsive computing* (Scott et al., 2015); Participatory Action Research (PAR), place-based education
Dialectical Stance	*none explicitly mentioned, but some implicit in several studies using many or all of the above philosophies*

Note. Some frameworks incorporated *more than one philosophy*, so repetitions are deliberate. Inter-rater reliability was 0.92 for assigning frameworks to philosophies. * = As will be detailed in Section 3.5, culturally responsive *schooling/education* is not consistent with culturally sustaining pedagogy. However, culturally responsive *computing* is consistent with culturally sustaining pedagogy.

3.1 *Pragmatism-of-the-Right*

Pragmatism-of-the-right maintains "a moderately strong form of realism, and a weak form of pluralism" as it pursues practical ends (Onwuegbuzie & Frels, 2013). Of the three papers featuring pragmatism-of-the-right, all drew from Román-González's (2015) Computational Thinking Test (CTt), including one paper by Taylor and Baek (2019) and two papers by Román-González et al. (2018). Exclusive use of the CTt would place a study solely in the category of pragmatism-of-the-right. Indeed, Román-González et al. (2017) themselves acknowledge that the CTt "is heavily focused on 'computational concepts', only covers 'computational practices' partly, and ignores 'computational perspectives'" (p. 445), consistent with emphasis on the individual-level rather than the micro-level and beyond. However, all three of the studies in this section engaged with additional paradigms, meaning they qualify as taking a dialectical stance. Therefore, in subsection 3.6 we will return to these three studies, but for now we focus on their pragmatic elements.

Taylor and Baek (2019) examined outcomes related to "robotics performance, computational thinking skills, and learning motivation towards computer programming" (p. 100) with 191 fifth- and sixth-graders in suburban Idaho, USA, per effects of gender (female or male), grouping (fixed roles, rotating roles, or no roles), and interactions thereof. Robotics performance was assessed per a four-point rubric with three categories, including a mix of more objective and more subjective criteria (detailed in subsection 3.6 below). They did not mention additional demographic information such as race/ethnicity, socioeconomic status, cultural or linguistic background, and so on. Consistent with a more realist approach, the writers chose to limit the number of categories for the analyses of variance (ANOVAs) performed, perhaps to increase statistical power for their sample size.

Román-González et al. (2017) administered the CTt alongside three cognitively-oriented assessments, along with some non-cognitive factors explored in a later paper (2018), to participating Spanish 5th to 12th graders ranging from sample sizes of around 100 to over 1000 for the various tests. The researchers used dichotomized gender and three age/grade ranges when running their various analyses. Ultimately they arrived at a "nomological network of CT including cognitive and non-cognitive factors" (p. 456), per various measures of ability (numerical, problem-solving, reasoning, spatial, and verbal), personality (Barbaranelli et al., 2003), and self-efficacy (Román-González et al., 2018). The nomological network, with a mix of relatively high or low correlation factors and significance levels, seeks to establish CT as its own "thing", distinct from generalized abilities, overall personality, or computing-specific self-efficacy.

Repeating the caveat that the above three studies engaged some additional paradigms, we now proceed to a variety of pragmatism with more-balanced treatment of realism and pluralism.

3.2 Pragmatism-of-the-Middle

A more moderate approach to pragmatism, *pragmatism-of-the-middle*, leverages a balance of pluralism and realism as it uses "observation, experience, and experiments" to move from "Lowercase 't' truths", of a preliminary nature, towards "Capital 't' Truth", which might only be known "at the end of history" (Johnson & Onwuegbuzie, 2004, p. 18). Pragmatism supports "shared values such as democracy, freedom, equality, and progress" (p. 18), which are often endorsed by regional, national, or international curriculum frameworks, albeit sometimes in ways that are racially and ethnically colorblind or overly individualistic (A. J. Rodriguez, 2015).

Studies mentioned seven international- or national-level curriculum frameworks or standards (see Table 3). In general, the frameworks and standards speak of "all" students/learners (equality), have public review phases (democracy), and purport to be improvements upon previous documents (progress). They tend *not* to speak of "each" student/learner (equity), maintain cultural, linguistic, or racial/ethnic diversity of their primary authors (decolonialism, anti-imperialism, etc.), or directly address structural and institutional inequities and inequalities (liberatory pedagogies, anti-racism, etc.), each of which would indicate a more transformative-emancipatory approach (see subsection 3.5). Usually the frameworks or standards were mentioned briefly, most often with regards to interventions being influenced or aligned thereof.

Sometimes the curriculum frameworks and standards were used as points of departure for conceptual frameworks. For example, Park and Park (2018) created a CT Practices Framework (CTPF) specific to integrating CT in programs of science, technology, engineering, arts, and mathematics (STEAM). In working with students in (the Republic of) Korea across four grade bands, they found that the CT practice of *parallelization* from the

Computer Science Teachers of America (Seehorn et al., 2011) did not fit in STEAM programming, but a process of *generalization* did fit. In other words, generalization was more practical to include than was parallelization. Another framework was created by Weintrop et al. (2016) in collaboration with practitioners, based on the Next Generation Science Standards (NGSS Lead States, 2013). Their *CT in Mathematics and Science Practices* taxonomy groups 22 practices into four major categories: data practices, modeling and simulation practices, computational problem-solving practices, and systems thinking practices. Weintrop and colleagues were explicit in stating that they hoped their taxonomy would be useful "for a diverse set of educational stakeholders including teachers, administrators, curriculum designers, assessment developers, and education researchers" (p. 129), later providing detail as to the practicality for each audience. Had the overall focus of the paper been case studies for these various stakeholders, we would have seen the approach of communities of practice, the research philosophy we next present.

3.3 Communities of Practice

Taking a *communities of practice* approach is "consistent with pragmatist philosophy" (Onwuegbuzie & Frels, 2013, p. 10), but might allow for more nuance via philosophical plurality at various levels of development (Bronfenbrenner, 1993). In reviewing articles for this paper, we noticed a distinct difference between studies that emphasized the individual level as situated in smaller communities (e.g. classrooms; "individual- to micro-level focus") compared to studies that had strong foundations in regional, national, or cultural contexts ("macro- to individual-level focus"). In our nomenclature, the higher priority is reflected in the first word (i.e. "individual . . . " and "macro . . . "); as a consequence, the first category is ascending in scale, and the second category is descending in scale ("individual- to micro-level focus" and "macro- to individual-level focus", respectively). While not exactly synonymous with constructivism, social constructivism, or interpretivism, the communities of practice approach is consistent with many aspects of those philosophies.

3.3.1 Individual- to Micro-Level Focus

In the 20 reviewed studies, the vast majority of frameworks for communities of practice took individual students as their primary unit of analysis, giving secondary consideration to the contexts of small groups, class sections, schools, localities, and so on. Even when students were working in pairs or teams, assessments were conducted at the individual level. For example, Taylor and Baek (2019) studied a *team*-based robotics project, but *individually* administered three assessments. However, students were assessed on their "group contribution" (p. 102), or how they participated themselves *and* encouraged teammates to participate.

One framework that proved particularly versatile was the Computational Concepts, Practices, and Perspectives framework (CPP) of Brennan and Resnick (2012). The four papers that used this framework varied in their emphasis on the three dimensions, sometimes explicitly and other times implicitly, as detailed in the following subsection.

3.3.2 Macro- to Individual-Level Focus

Continuing our findings from studies using the CPP framework, we note how Martin and Jacobsen (2018) forwarded broad ethical concerns of national and international scales (i.e.

macro-level), as they leveraged the Scratch programming language for youth in grade 8 to explore health benefits and privacy concerns of medical devices. Their study was one of few that went beyond asking the pragmatics of *can* we use a given computing method, extending inquiry to the ethics of *should* we use that method. In this case, the perspectives provided a foundation upon which youth engaged with concepts and practices. A perhaps even broader-scale foundation is found in the work of Searle et al. (2019), who worked with non-dominant girls using electronic textiles to explore their cultural backgrounds and understandings. Searle and colleagues found that some 8th graders made deep connections with their own identities and those of participating adults, shifting the perspective from "'normal' science classes" (p. 52) to a view that included art, stories, and relationships.

3.4 Critical Realism

Having discussed the minimally pluralist *pragmatism-of-the-right*, the moderately plural *pragmatism-of-the-center*, and the more pluralist *communities of practice*, we now arrive at a research philosophy that deliberately positions itself as a "middle way between empiricism and positivism on one hand and anti-naturalism or interpretivism on the other" (Zachariadis et al., 2010, p. 4).

Critical realism acknowledges both physical reality and our inability to perceive or even observe some of it, as well as social processes and causation, without anything so general as "social laws" (Zachariadis et al., 2010, p. 4). For this subsection, we continue with a relatively abstract application of the Computational Concepts, Practices, and Perspectives framework by Brennan and Resnick (2012), then delve deeper into two more abstract concepts. Returning to Searle et al. (2019), we now emphasize an insider(s)|outsider(s) theme shown in at least two key instances. First, the three authors acknowledged that for them, as well as the extended research team, "in both communities, we were considered outsiders", in part due to their positionality as White women working with Indigenous communities (p. 50). Further, as outsiders the authors decline to write the name of "an Indigenous concept expressing the idea of family and cooperation" (p. 52). While Searle and colleagues explicitly identify as operating with an interpretivist paradigm, their declining shows the critical realist idea that there is no social "law" transcending communities.

In a study with grades 6 and 7 students in the town of Terlizzi, Italy, the scholars Rossano et al. (2018) asked not only questions about students' "e-skills", but also questions about how "enjoyable" or "engaging" the project was (p. 267). The researchers could have used more standardized instruments, particularly for student engagement (Fredricks et al., 2016). However, they chose to keep a more abstract and pluralist approach, implying that engagement is not something that can be wholly perceived, observed, or both. At the same time, Rossano and colleagues acknowledged the value of more realist approaches, including the idea that "experimentation with a larger sample should be conducted" (p. 269).

The final study that we will emphasize for critical realism was conducted by Gautam et al. (2017) who worked with 7th graders in "a low-resource setting" located 14 kilometers outside Kathmandu, Nepal (para. 1). They used "multiple representations, both on and off the computer" (para. 6) to examine an ambiguously operationalized concept of *apprehension*. In tension with using a standardized "attitudinal assessment [of] self-confidence with, interest in, values for, and identification with computing" (para. 12), evidence for apprehension was more situated, including the observation that "three groups hesitated to change slider values during the initial exploration out of fear of 'making the system go bad'". (para. 14) While the system in question was merely a simulation (i.e. it would not affect the students' physical surroundings), the only partially-understood mechanisms – namely, what "go bad" entails, and why it mattered to students – are consistent with a critical realist view that we are incapable of fully understanding social causes and effects.

3.5 Transformative-Emancipatory

A *transformative-emancipatory* approach argues that none of the previous four philosophies goes far enough to address and redress systemic and institutional inequalities and inequities. This approach views knowledge as constantly influenced by human interests, power, and social relationships, and holds that research should be conducted in emancipatory, anti-discriminatory, and participatory ways to improve the conditions of oppressed populations (Mertens, 2003). Consistent with the metaparadigm of critical dialectical pluralism (Onwuegbuzie & Frels, 2013), we give extra attention to this section, with the goal that it "advances and sustains an egalitarian society" (p. 14).

Returning once again to the study of Searle et al. (2019), this time we focus on its enactment of *culturally responsive computing* (Scott et al., 2015). Despite the term "responsive", which Paris (2012) argues is not as conceptually appropriate as the word "sustaining" (and we concur), the five tenets of Scott et al. (2015) use terminology like "transformational use", "intersecting sociocultural lines", and "who creates, for whom, and to what ends" (pp. 9–10). These phrasings are consistent with both "maintaining" *and* "extending" practices (Paris, 2012, p. 94). Searle et al. (2019) particularly focus on technology as "a vehicle through which students can express and explore their intersectional identities" (p. 45), rather than merely showing "tolerance" (Paris, 2012, p. 95) for said identities. Ultimately, the intervention was successful in (re)engaging girls in intersectional ways (i.e. along with gender, including class and race/ethnicity), unlike studies that focus on one aspect of identity alone (often binary gender) and ignore compound discrimination (Cho et al., 2013).

One study not yet discussed is a decidedly cosmopolitan investigation by Motschnig et al. (2018) who referenced a variety of national and transnational frameworks in their partnership with students aged 7–12 in an unnamed locality of Austria. (Per our review criteria of ages 10–15, we focus on the students aged 10–12.) Taking care to align the project with guidelines from ACM Europe, Informatics Europe, and the European Union, the collaborators supported students in using a design process of *empathizing, defining, ideating, prototyping*, and *testing* per the US-based Stanford Design Thinking Method for Kids (Falck, 2013). In particular, *empathizing* goes beyond being "relevant" or "responsive", empowering students to engage in self-sustaining activities. In this case, they used Minecraft Education Edition™ world-building and -interacting software to (re)imagine a *Classroom of the Future*. Further, Motschnig and colleagues took an approach of Participatory Action Research (PAR) to ensure that teachers would remain involved in the project and "improve sustainability" during the intervention and beyond (para. 1). Thus, both students and teachers were involved in transformative-emancipatory ways.

Another study not yet detailed is by Gendreau Chakarov et al. (2019), who partnered with grades 5–8 students in a "large urban public school district" of an unspecified municipality (p. 820). While no place-names are mentioned, a model of *place-based education* ensured that the two projects were of substantial interest to the local community. In particular, a project on mold growth in students' schools culminated with youth making plans and recommendations to their custodians and principals, as well as offering ongoing monitoring of a concerning area. In these ways, rather than focusing on existing classroom contexts, the partnership sought to transform problematic environmental conditions at an institutional level. It should be noted that the exo-level focus was nonetheless commensurate with individual- or micro-level gains; students reported feeling "like scientists", "excited", and that the projects "mattered" to themselves and to their class as a whole (p. 820). Further, in studying engagement as an outcome for both students and teachers, the researchers demonstrated a valuing that the intervention could transform the classes, schools, and beyond. Though the authors do not label their work as participatory, their enactment of design-based implementation research (DBIR) was one that deeply "involves the teachers' expertise . . . and . . . ensures that the resulting storyline units are both feasible and appropriate" for teachers, students, and their local contexts (p. 819).

While it is not inherent that a transformative-emancipatory approach should be part of a dialectical stance, in these three studies the authors did engage with multiple additional paradigms, notably pragmatism-of-the-middle and communities of practice. Thus, in the following subsection we will return to the same three studies, but with a meta-perspective on how the studies engaged their multiple research philosophies to arrive at deeper and more nuanced understandings of the locally situated interventions.

3.6 Dialectical Stance

A *dialectical stance* views engagement with paradigmatic differences as being generative towards answering a given research question or questions (Onwuegbuzie & Frels, 2013). There are variations of dialectical stances, with approaches that focus on differences in data, paradigms, or power structures – respectively, the *dialectic stance* of Greene and Hall (2010), *dialectical pluralism* of Johnson (2017), and *critical dialectical* pluralism of Onwuegbuzie and Frels (2013). Given our goal of more culturally sustaining pedagogy, an emphasis on power structures was used in our analyses. We first revisit the three studies from the pragmatism-of-the-right subsection, whereafter we will re-encounter the three studies from the transformative-emancipatory subsection.

Returning to the robotics study by Taylor and Baek (2019) with 5th and 6th graders in an Idaho suburb, we recall that their treatment of robotics performance had a strong association with pragmatism-of-the-right. However, part of the rubric had a more pluralist component, namely an item where students self-assessed whether they used "efficient coding", were "not as efficient as I could have been", and so on (p. 102). Amidst many concrete criteria (performance), this relatively subjective item expands in a critical realist manner, by foregrounding uncertainty of what any given learner "could have been". Further, the authors' conception of motivation, per the Learning Motivation towards Computer Programming test (Law et al., 2010), had a decidedly communities-of-practice approach, examining a combination of more intrinsic and more extrinsic factors, more cognitive to more emotional, and more individual to more social. While the authors could have gone further from a transformative-emancipatory lens (e.g. consider identity beyond binary gender), their work to date has laid a strong foundation for further investigations.

We will discuss in tandem the two studies by Román-González et al., 2018, as the second is a logical extension of the first. Though the two studies are firmly rooted in pragmatism-of-the-right, they form a base for more transformative-emancipatory work, going beyond semantics of equality ("all", "underrepresented", and so on) to address, if not yet redress, issues of equity. For example, Román-González et al. (2017) explicitly mention exceptional learners, not from a deficit-based frame of "disabilities", but recognizing "special needs", then taking the relatively rare extension to "students with high abilities" (p. 687). Further, rather than focusing exclusively on outcomes – and ignoring inequitable contexts thereof – Román-González et al. (2017) explicitly name "stereotypes", and they hint at sexism and ageism when discussing variations in confidence and self-efficacy (p. 443). Thus, it is hopeful that their Computational Thinking Test (CTt) will continue to be studied and refined for "massive screenings and early detection" in a proactive way (Román-González et al., 2017), allowing for earlier intervention that might make it easier to study and close gaps due to inequities and inequalities outside of schools (housing, healthcare, stereotype threat, etc.).

Finally, we return to the three studies from the subsection on a transformative-emancipatory approach. While some transformative-emancipatory scholars have criticized pragmatism for not going far enough to address inequalities and inequities (e.g. Mertens, 2003), the three studies discussed here had pragmatic elements that did not compromise their sustaining of students, teachers, classes, schools, communities, and cultures. For example, Searle et al. (2019) acknowledged the practicality of Internet connections while at the same time noting disproportionate access based on income, race/ethnicity, and geography. Further, they recognized the value of technology while criticizing pedagogies wherein "students in high- and middle-income areas are taught to be critical thinkers and producers" yet "students in low-income areas are taught to be uncritical consumers" (p. 43). As for Motschnig et al. (2018) their participatory action approach had a clearly pragmatic goal, as per their research question, "How can computational thinking, digital- [*sic*] and interpersonal competences be effectively promoted in schools (K2-K6) with traditional structures?" (para. 19) Similarly, Gendreau Chakarov et al. (2019) were very mindful of existing structures, namely school science curricula and the participating teachers' need to align to the Next Generation Science Standards (NGSS Lead States, 2013). Thus, the studies that did the most to "maintain the practices of their students" also succeeded in "extending their students' repertoires of practice to include dominant language, literacies, and other cultural practices" (Paris, 2012, p. 95).

3.7 Closing Comments for Results: From Paradigms to Metaparadigm

In this section, we sought to counterbalance some of the dominant research philosophies of teaching CT in required science and engineering classes with young adolescents. In particular, we gave disproportionate attention to critical realist, transformative-emancipatory, and dialectical philosophies. This approach is consistent with the metaparadigm of critical dialectical pluralism, which seeks to "privilege those paradigms or worldviews that promote and sustain an egalitarian society", the same paradigms and worldviews that are often neglected due to their relatively high demands for participants at multiple levels, funding thereof, and time commitments therein (Onwuegbuzie & Frels, 2013, p. 14). For example, Searle et al. (2019) noted that "[their] relationship with [the participating school] took two years to establish". (p. 50) Nonetheless, we concur with Onwuegbuzie and Frels (2013), who argue that "long-term beneficence" (p. 22) for participants is worth the investment of time and energy.

4. Discussion

In this paper we presented an analysis of the research philosophies reflected in 20 studies across 18 papers, all for teaching computational thinking and practices in required science and engineering courses with young adolescents (ages 10–15). Building upon literature reviews conducted by Lockwood and Mooney on how computer science is taught in secondary education (2018) and all education (2017), we extended their work temporally and elaborated it axiologically. Our landscape review analyzes and synthesizes pluralistic philosophies that nonetheless result in some shared implications for research and practice.

In this section we highlight some key implications for conceptual and empirical research, recognizing that the two approaches can synergistically support each other (sometimes in the same study). We then conclude with a return to the "many and one" theme with which we began the paper.

4.1 Implications for Empirical Research

As mentioned in the Abstract, we hope that highlighting exemplars in this paper will promote future research that is culturally sustaining (Paris, 2012), namely by advancing narratives that pluralistic research on teaching CT in science in engineering classes is not only possible, but it has already been realized. In particular, we sought to foreground examples that were true to a transformative-emancipatory approach, yet still engaged additional research philosophies in generative ways (Gendreau Chakarov et al., 2019; Motschnig et al., 2018; Searle et al., 2019). Also, we aimed to forward examples of studies with a more realist and less pluralist *pragmatism-of-the-right* core, which nonetheless engaged with philosophies of a more critical realist or communities of practice approaches (Román-González et al., 2017, 2018; Taylor & Baek, 2019). In general, the aforementioned studies involved extended teams of stakeholders (students, teachers, researchers, administrators, community members, and so on); future work would do well to use as a model the partnerships exhibited in those papers, as investments of resources will ensure longer-term beneficence for the young learners at the heart of the work (Onwuegbuzie & Frels, 2013).

In addition to exemplar studies, we found that two frameworks were common to multiple research philosophies. The Computational Concepts, Practices, and Perspectives framework of Brennan and Resnick (2012) was featured in studies oriented in three different philosophical approaches, and likely could be adapted to additional philosophies. Also, the CT in Mathematics and Science Practices taxonomy by Weintrop et al. (2016) was used in studies with multiple research philosophies, and it has strong roots in practice given its development with practitioners alongside researchers. Either of these frameworks could serve well for empirical studies looking to engage in reflexivity between practice and theory.

To address inadequate systemic funding mechanisms that lead to unequal access of computing experiences (Blikstein, 2018), dominant norms and power structures within institutions and societies (S. L. Rodriguez & Lehman, 2017), and institutionalized deficit-based approaches to cultural practices, especially for immigrant students and students of color (Paris, 2012), future empirical work would benefit from a critical dialectical pluralist stance (Onwuegbuzie & Frels, 2013). Such work could address inequities related to race/ethnicity, gender, socioeconomic status, and additional identity markers, in intersectional ways that unite rather than divide students' multiple dimensions of identity (Cho et al., 2013; S. L. Rodriguez & Lehman, 2017).

4.2 Implications for Conceptual Research

Throughout this paper we have argued for more pluralistic and critical philosophical approaches to research on teaching computational thinking in required science and engineering classes with young adolescents. This argument is supported by the empirical works we have detailed, as well as the conceptual works to which we have alluded. Given our background in mixed research, we have grounded this landscape review in the methodological scholarship of that field. However, in recognition that mixed or multiple research methods might not be ideal for any given research question(s), we note that Onwuegbuzie and Frels (2013) advocate for, and provide examples of, effective use of critical dialectical pluralism in mono-methods studies.

We posit that critical dialectical pluralism can be a good fit for both conceptual and empirical work. However, we are unaware of any meta-analyses that leverage critical dialectical pluralism as a framework. We hope that meta-analytic specialists with goals of more egalitarian societies, "both universalistic theoretical knowledge and local practical knowledge" and "culturally progressive research" (Onwuegbuzie & Frels, 2013, p. 14) will develop ways to integrate critical dialectical pluralism into their work.

One observation that merits further analysis is the separation between transformative-emancipatory scholars and scholars holding most other philosophies. We find with regret that concerns held by transformative-emancipatory scholars over systemic inequalities and inequities are not explicitly shared by scholars from other paths, whose interests heavily lie in finding practices that broaden participation in computer science itself. While the study of such practices certainly offers valuable insights into the dissemination of computer science education, we posit that the ultimate goal of computer science is to create a more equitable society, which begins with explicitly taking a critical stance.

Finally, we want to emphasize that being "balanced" and "equal" – or worse, ignoring various facets of intersectional identities – is not enough to disrupt entrenched structural and institutional inequities and inequalities. If we are to address and redress social injustices, we must reject a "discourse of politeness" (A. J. Rodriguez, 2015, p. 1038) and meet head-on the multifaceted barriers to more just communities and societies.

4.3 Implications for Practitioners and Teacher Educators

We also want to call to attention that our work is evidence that teacher education and practice should be revised forward, because "maintaining the heritage cultural ways of students of color" (p. 88) and encouraging students to critique dominant power structures

(Paris, 2012) requires explicit support from educational practitioners to meaningfully maintain and sustain students' cultural heritage in words and in deeds. A stance of critical dialectical pluralism allows teachers to freely draw upon a range of philosophies to deeply examine the purpose of integrating computational thinking in science and engineering, and also to reimagine the learning outcomes they want to see in a way that challenges the status quo and moves the next generation closer to an egalitarian society (Onwuegbuzie & Frels, 2013).

Meanwhile, we want to remind educators of the danger of broad or "umbrella" uses of terminology, which sometimes give a false sense of security (Paris, 2012, p. 94). As pre-service teachers nowadays continue to find it difficult to connect their training with long term professional development from the moment they graduate (Campbell & Walta, 2015), teacher education programs need to take actions to ensure that their culminations are not the end of pursuing culturally sustaining teaching and learning. The illusionary hope of expecting courses in multiculturalism to fulfill the task of raising pre-service teachers' critical consciousness (Xu et al., 2016) must be replaced with holistic curricula and longitudinal professional support, if we are to truly advance the teaching of computational thinking in science and engineering classes towards promoting a more just society.

4.4 Closing Comments: Many and One

In closing, we note the fractal nature of "many and one" (Paris, 2012, p. 95) when teaching CT in required science and engineering classes with young adolescents: many learners, cultures, and research philosophies converge into one curriculum design, one educational unit, or one research project . Pluralisms of intersectional identities are here to stay in our worldwide, globalized, unjust society; we must engage these pluralisms to make that society more egalitarian for all learners and each learner.

Acknowledgments

We wish to acknowledge participating youth and adults who continually and dialectically engage in ongoing empirical and conceptual transformations. Several members of our research group shaped earlier versions of the manuscript, including Mike Barnett and Helen Zhang. We thank the editors and anonymous reviewers for their generative feedback.

This work was supported in part by the National Science Foundation through the ITEST and DRK12 programs, grant #s 1759152 and 1814001. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Disclosure of potential conflicts of interest

No potential conflict of interest was reported by the author(s).

Notes on contributor

David W. Jackson studies, co-designs, and implements learning environments that promote student engagement in science and engineering, particularly for young adolescents, in ways that forge dynamic solidarities between historically marginalized and dominant communities. He currently is

After-School STEM Coordinator with Kennedy and McDevitt Middle Schools, Doctoral Candidate/ Researcher with Boston College, and Field Instructor with Brandeis University.

Yihong Cheng is a doctoral student in the Lynch School of Education and Human Development at Boston College. Having earned his B.A. in physics and M.A. in multicultural teaching and learning, his work revolves around researching on and designing culturally sustaining STEAM learning environments for young adolescents and related professional trainings for teachers.

ORCID

David W. Jackson http://orcid.org/0000-0002-2285-7545

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