

Building upon the CAPE Framework for Broader Understanding of Capacity in K-12 CS Education

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ABSTRACT

Research Problem. The CAPE Framework has been used in multiple studies to situate capacity-building efforts within schools to offer equitable student access to and participation in K-12 computer science (CS) education. CAPE defines four major components of capacity, access, participation and experience. However, to define what each of the CAPE components can entail, well-defined subcomponents are needed.

Research Question. Our research questions for this study were: What are the possible subcomponents for Capacity in the CAPE framework? and How feasible is it to use the newly defined subcomponents in a gap analysis study?

Methodology. We conducted a qualitative content analysis by creating a codebook from an existing data framework and literature review. We reframed earlier findings on factors that influence student learning and academic achievement into the CAPE.

Findings. We vetted an expanded framework that includes eight Capacity subcomponents, a third (categories) layer and a fourth (subcategories) layer that can be used to disaggregate the many elements that comprise Capacity. For our trial analysis of 196 articles, we added several codes at the category and subcategory level, but found no gaps in the codes for our *a priori* defined subcomponents.

Implications. The extended Capacity framework can be used by others to inform its usage and develop a consensus of what is included within each subcomponent for Capacity, develop instrumentation and protocols for exploring Capacity at a more granular level, conduct scoping and literature reviews, and understand how various variables play a part in the CS educational ecosystem.

CCS CONCEPTS

• **Social and professional topics** → **Computer education; Computer education programs; Computer science education.**

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KEYWORDS

CAPE, education, primary, secondary, K-12, capacity, access, participation, experience, education, subcomponents, equity

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1 INTRODUCTION

Computer science (CS) education has matured from an elective or specialist course to a more fundamental course in general primary and secondary education. The research of CS course deployment, integration in other subjects, teaching methods, and learning outcomes has engaged an increasingly large part of the scholarly work of record over the last 10 years. As the volume and diversity of CS education research increases, the research community must also apply existing as well as new methods to analyze, disaggregate, create frameworks, and apply those frameworks to the corpus of research available.

There have been numerous articles published that seek to synthesize the state of the field [2, 9, 15] or individual topics [14, 25]. This includes the emerging CAPE framework, which explores four areas of computing education: the Capacity for computing education within a school, district or region; who has Access to computing education; who Participates in the computing education; and the Experiences of the learners who are participating in CS education. The framework has been used in multiple research and evaluation analyses and is proving to be useful in critically examining who benefits from CS education and who misses out [10, 19, 26].

In this paper, we describe our broadening of the CAPE framework [11] so that it is centered beyond the academic content or institutional level (primary, secondary, post-secondary) to areas of implementation necessary for equitable outcomes for youth in CS learning opportunities. Our research question is: *What are the possible subcomponents for Capacity in the CAPE framework?* To answer our research question, we first created a codebook *a priori* based on CAPE and exiting literature, then classified 196 articles using the new codebook. This is a first step in creating a full scoping review of the literature to identify gaps in the CS education research

literature corpus and inspire researchers to consider exploring the unanswered questions in the field. Our new codebook can be used by researchers and evaluators to more deeply understand the various individual pieces that comprise Capacity, including how these various pieces are defined and play a part in the CS educational ecosystem.

2 BACKGROUND

Capacity is perhaps the least studied aspect of the CAPE framework, and yet is the bedrock on which implementation relies (Figure 1. In 2018, Blikstein and Moghadam highlighted “implementation considerations” related to “systemic obstacles” as key components of equitable CS education at scale [2]. When exploring the capacity of these systems and institutions, we need to question the policy environment that resources the institutions, the administration who makes decisions about implementation, and the availability of resources such as teachers, curriculum, or equipment for offering CS coursework, all of which are driven in part by sufficient funding. Ongoing work has found that district leaders have difficulty defining what counts as CS [24], stating what is going on in their own buildings [7], and conceptualizing how broadening participation in computing and equity intersect with larger district plans [24].

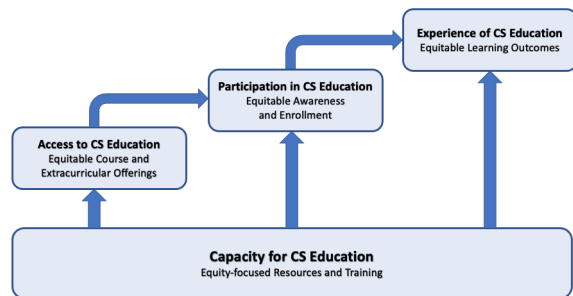


Figure 1: CAPE framework reframed to reflect Capacity as the foundation for success for all other components.

Historically marginalized populations encounter systemic barriers at the institutional level affecting their education outcomes [1, 3]. There is a small, but growing, body of literature to help school districts navigate the myriad of choices necessary to implement CS education equitably, create project goals, use instructional leadership strategies, identify relevant curriculum and learning pathways, create professional development (PD) plans, and secure necessary funds and resources to implement these ideas [3, 12, 21, 22].

As an equity-focused framework, the Capacity aspect of institutional implementation calls into focus the notion of assets and resources as a key component of equity. K-12 education in the United States (and across the globe) has often been called out for inequities that exist due to geographic and community factors such as community wealth and population demographics [27]. The term capacity, however, is broad and components of capacity have been represented in a variety of ways in CS education literature [2, 9]. In this paper we lay out the details of developing a disaggregation of capacity grounded in research and literature, and contribute to the community through applying the codebook against current articles.

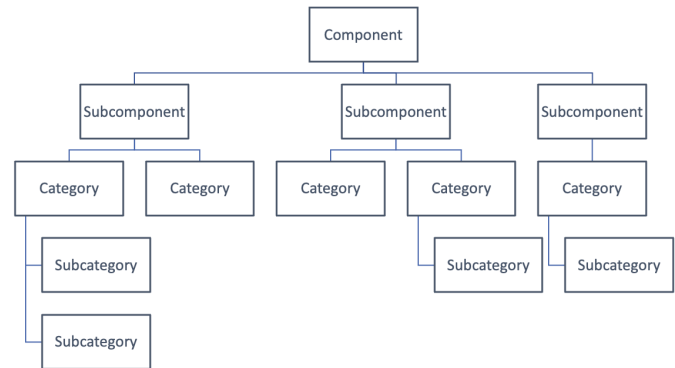


Figure 2: Hierarchical structure for the codebook. In this paper, we describe subcomponents and categories.

3 METHODOLOGY

To answer the research question, *What are the possible subcomponents for Capacity in the CAPE framework?*, we engaged in a process to create a codebook *a priori* and then use the codebook to engage in a deductive coding process [20]. To answer our second research question, *How feasible is it to use the newly defined subcomponents in a gap analysis study?*, we piloted the codebook in a gap analysis conducted over a set of articles.

3.1 Developing the codebook

During this collaborative process, one of the researchers seeded the Capacity codes with analysis of over 1,000 papers in the K-12 CS Education Research Resource Center corpus. This gave us an initial set of 93 codes (at the subcategory level) to start. Immediately following, two of the researchers engaged in finding previous literature relevant to Capacity. This included [4, 8, 16], which all provided insight and particular forms of Capacity that were then added to our codebook. The two researchers met together to discuss the multiple levels of analysis (subcomponents, categories, and subcategories as shown in Figure 2) being developed when conducting the first draft of code development and defining each code created.

To begin the process of deductively creating the subcomponents and categories for capacity, we first added three subcomponents based on [11]’s suggestion that “...[t]hese resources may include faculty, funding, and policies that make implementing CS instruction possible and inclusive.” [11, online] Thus, we placed *Human Resources*, *Funding*, and *Policies* as three subcomponents under Capacity. Policies stand out as an important subcomponent under Capacity since policies influence much of what is mandated to be taught in K-12 schools [24].

We recognized that *Curriculum* and related materials are necessary for teaching, and these materials can be offered through various instructional strategies [5, 6, 18]. We also recognized that *Standards* often do, or should, play a part in developing policies and curriculum [6]. Finally, a *School’s Environment and Culture*, *Instructional Strategy/Pedagogy* and *Community Environment, Culture & Ideology Supporting CS Education Implementation* are important as well, and we were able to build categories for these using our

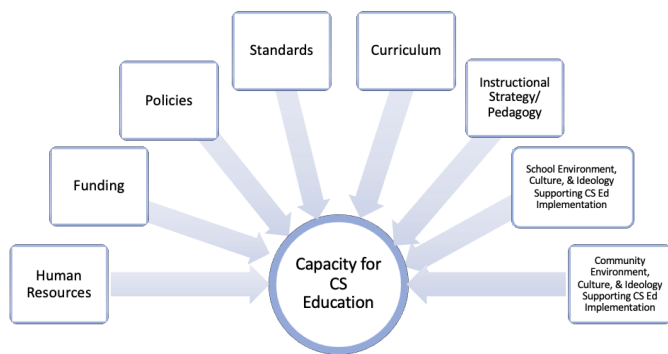


Figure 3: Capacity and its subcomponents.

previous work developing a classification system for articles [17], which was informed by Lee and Shute [16] and Farrington et al. [8]. For example, Lee and Shute’s paper directly links variables at the capacity level to academic achievement, including teacher variables, administrator variables, and family/peer influences. We drew from this research by extracting these variables and placing them as codes in the codebook at the relevant category and subcategory level.

After completing the first draft, the two researchers shared the draft and discussed it with four additional researchers on the team. During these collaborative conversations and partly based on our own research literature outside of the scope of the corpus that we intended to investigate, we made adjustments to the multiple levels of codes, discussed clarifications for each of the descriptions, and made a plan for a second draft of the codes. Four of the researchers took this feedback and completed a second draft, which was then shared and discussed with the full team again. Once a third draft was completed, all of the codes were sent to the entire team for an asynchronous final review. At this point, our codebook consisted of 177 codes for capacity. Our resulting codebook (down to the category level only) is presented in Table 1.

3.2 Vetting the codebook

Once the codebook was created, we identified 11 CS education-oriented journals and conferences from which the codebook would be tested using the publicly-available K-12 CS Education Research Resource Center dataset. These included the following publication venues: ACM International Computing Education Research, Innovation and Technology in Computer Science Education, SIGCSE Technical Symposium, and Transactions on Computing Education; IEEE Frontiers in Education, Global Engineering Education Conference, Transactions on Education, and RESPECT; Journal of Educational Computing Research; Koli Calling; Taylor & Francis’ Computer Science Education; and Workshop in Primary and Secondary Computing Education (WIPSCE).

We tested the codebook against recent articles from 2019 and 2020. We found 196 articles that met the following criteria:

- Described or evaluated a computing activity or process,
- Targeted K-12 educational ecosystem (specifically or more broadly), and
- Designed to teach computing or computational thinking.

Table 1: Capacity Subcomponents and Categories.

Subcomponents	Categories
Community Env., Culture, & Ideology Supporting CS Ed Implementation	Extracurricular Providers Families Media Student Influences
Curriculum	Assessments CS curriculum Course Descriptions CT curriculum Prerequisites Resource materials & facilities for teaching CS
Funding	Origination Type
Human Resources	Administrators Guidance Counselors Instructional Supervision Library/Media Specialist Professional Development Teachers Teachers - Special Education
Instructional Strategy, Pedagogy	Student-centered Teacher-centered
Policies	Core graduation requirements Dual credit offerings Higher ed admission requirements Required # of course offerings Pathways Teacher
School Environment, Culture, & Ideology Supporting CS Education Implementation	Academic Emphasis Belongingness Career Guidance Classroom behaviors Classroom Cultures Diverse Professionals and Role Models Providing Exposure to Range of CS/Tech Careers Family and Community Cultural Assets Incorporated into CS Classrooms Inclusive and Equitable Power dynamics Racism in CS and Anti-Racist Practices Sexism in CS and Anti-Sexist Practices Pedagogy and Curriculum are Rigorous, Relevant, and Encourage Sociopolitical Critiques Student Voice, Agency, and Self-Determination Title I Status/Socio-economic status
Standards	CSTA K-12 ISTE Standards State-created Standards Other

We included experience reports, research papers, and journal articles in our corpus of articles to review. Regardless of their type, we reference them as "articles" throughout this paper.

Our coding process followed the Framework Method [13] and was as follows:

- Four researchers coded the first two articles together as a group for norm setting.
- The researchers then coded 16 articles, with each of the 16 articles being coded by two researchers.
- The researchers then met to discuss the 16 articles. Any anomalies that arose in the coding process were discussed until the researchers gained a consensus on the codes for that paper.
- The last two steps were repeated until all the articles were coded.

We used the Quirkos qualitative analysis tool to code the articles [23]. Once the articles were coded, we brought the results in a MySQL database and conducted our analysis using SQL queries.

Of the articles that we found, during the coding process one article could be studying multiple areas and thus was coded accordingly. However, we also note that one article may only focus on one area, and that was also coded accordingly.

3.3 Positionality Statements

Four of the researchers undertaking this work are well-experienced researchers with deep understandings of the K-12 CS education ecosystem. Two researchers are newer to CS education research, but also have research experience, with one having extensive experience researching and evaluating programs in a large, urban K-12 district within the U.S. All of the researchers bring with them an equity-focused lens and apply it to this work. This has resulted in sharing of various factors that can influence building an education program that meets the needs of all students, and these factors were examined in light of existing literature to see which should be added as codes to the codebook.

4 RESULTS: PILOTING THE CODEBOOK

To explore our first research question, *What are the possible subcomponents for Capacity in the CAPE framework?*, we present the results of our usage of the codebook, what we learned about the codes, and the codes that we modified or added to build the codebook. We then discuss our findings of the gap analysis to explore our second research *How feasible is it to use the newly defined subcomponents in a gap analysis study?*.

4.1 Codebook

While we piloted the codebook to answer research question 2, we discovered several discrepancies in our codebook at the category and subcategory level only. Through the process of coding research, we only added one category: *Professional Learning Networks/Communities* to the *Human Resources* subcomponent.

Although subcategories are not presented in this paper, it is still worth noting that we added 25 subcategories across several categories, with the majority added to the *Instructional Strategy/Pedagogical Approach* category. From these, we removed

5 codes at the subcategory level and replaced them with better-formed codes, and this brought our total number of final codes to 196. Although we had started with a set of pedagogical subcategories based on the literature (including [18]), we significantly revised the *Instructional Strategy Pedagogy* subcomponent as we encountered articles that explored various types of pedagogy. Within this subcomponent's *Student-centered* category, we added several subcategories, including:

- Use-Create-Modify
- Predict-Run-Investigate-Modify-Make (PRIMM)
- Hybrid Environment
- Culturally-relevant/responsive pedagogy
- Project-Based Learning
- Block-based Programming
- Pen and Paper Exercises
- Games
- Reflective
- Symbolic (no text block-based)
- Text-based Programming and
- Visual (text block-based).

Upon further reflection, these additions make sense to the overall analysis process since the majority of the codes added were more generic to education in general, while the instructional strategies were mostly specific to CS education (e.g., block-based programming, symbolic programming).

We also added the subcategories *In-service Teachers* to the *Human Resources* -> *Professional Development* category and *Other* to the *Curriculum* -> *Resource materials and facilities for teaching* category. At the subcategory level for the *School Environment, Culture, & Ideology Supporting CS Education Implementation* subcomponent, we added the following subcategories as warranted while we reviewed the articles: *Teacher Incentives for PD*, *Teacher Advocacy*, *Teacher Anxiety (Computing)*, *Teacher Attitudes*, *Teacher Confidence*, *Teacher Enjoyment*, *Teacher Professional Learning Networks/Communities*, *Teacher Usefulness for Students (CS Learning)*, *Teacher Perspectives*, and *Teacher Usefulness for Teachers (CS Learning)*.

In several instances, we also refined our definitions for several of the codes to be clearer and more accurately reflect what the research study indicated. This also made the code definitions clearer for when we plan to use the codebook later and for future users of the codebook.

The current version of the codebook with all 196 codes is published at <https://csedresearch.org>.

4.2 Gaps in Capacity Research

The gaps in coverage at the category level for Capacity are shown in Table 2. While we found that 18 categories are covered in the 2019 and 2020 literature, in comparison to the 47 categories in the codebook that are presented in Table 1, the K-12 CS education research literature is significantly lacking with swaths of research topics in Capacity remaining unexplored.

Within the categories that have coverage, the two most frequently studied are student-centered instructional strategies, with nearly 41% (80 of 196) of the articles examining this topic and teacher related topics related to school environment, culture, & ideology examined in 37% (72 of 196) of the articles.

Table 2: Research coverage of 2019 and 2020 articles. Percentage is based on 196 articles in total.

Subcomponents	Categories	N	%
Community Environment, Culture, & Ideology Supporting CS Education Implementation	Extracurricular Providers	1	n/a
Curriculum	Assessments	3	2%
	CS curriculum	9	5%
	CT Curriculum	5	3%
	Resource materials & facilities for teaching CS	17	9%
Human Resources	Professional Development	11	6%
	Professional Learning Networks/Communities	2	%
	Teachers	11	6%
Instructional Strategy - Pedagogy / Pedagogical Approach	Student-centered	80	41%
	Teacher-centered	5	3%
Policies	Pathways	1	n/a
School Environment, Culture, & Ideology Supporting CS Education Implementation	Administrators	5	3%
	Guidance Counselors	1	n/a
	Inclusive and Equitable Classroom Cultures	18	9%
	Power dynamics	1	n/a
	Student Voice, Agency, and Self-Determination	1	n/a
	Teacher	72	37%
Standards	State created standards	2	1%

After these two categories, the topic areas studied drops significantly. Only 9% of the articles study inclusive and equitable classroom cultures, which starts to speak to how little equity is being examined in the research corpus.

Notably, there are few to no studies examining funding and its impacts at the federal, state, or district/school level. Other missing research that gives us pause include the lack of exploration on standards, Title I schools, core graduation requirements, higher education admission requirements, and guidance counselors. There were also no explorations published during this time period on the influence of families, media, and peers and how they support CS education of students.

5 DISCUSSION

In this pilot study, the Capacity codebook based on the CAPE Framework showed remarkable stability at the first three levels of the hierarchy (Capacity component, subcomponents, and categories). Only one category, *Professional Learning Networks/Communities*, was added to *Human Resources*. While there were several categories added at the subcategory level, that is expected as we continued to hone in on the specific scholarship available through this framework lens.

With respect to the results of the preliminary gap analysis across the 196 papers, through our searches, we know of no other research similar to this conducted within K-12 CS education research. The lack of a gap analysis on Capacity within the K-12 CS education

space means that this unique analysis will provide the first comprehensive examination of missing research that will be important for the education research community to grow.

Our codebook worked remarkably well for quantitative and mixed-methods research studies. However, when coding qualitative studies, we found that while the research study itself may be investigating a certain phenomenon or focus area, the results of coded interviews and materials could be quite broad. In these few cases, we used our best judgment to determine whether the research findings had enough detail to warrant being included in a certain subcategory or whether it should not be added. We were careful about this because we did not want the results of our gap analysis to overrepresent certain subcategories or categories.

While we present data from the codebook, additional data has been collected from the articles, including whether gender, race/ethnicity, and socio-economic status were analyzed, the demographics of the participants in the studies, and the CS concepts taught. This data will augment our analysis to determine how equity is considered further. For example, when considering the student-centered pedagogical literature, we will be able to understand which students are included (or are absent from) these studies, giving us a broader picture of where additional gaps are in the research.

As with any study, there were limitations to our trial of the codebook. First, we vetted the codebook against 196 articles from 2019 and 2020. Our final set of data will also include 2021 and potentially 2022 as we move forward with this research. Undoubtedly, additional codes will be found as the field continues to grow and the corpus of research starts to reflect that growth.

While we considered Capacity in this paper, we have started to investigate the scope of coverage with respect to Access, Participation, and Experience in the CAPE framework. Since Capacity is foundational to all three of these, understanding how findings from the Capacity research relate with these other components is not included in this paper, but will be important to explore in the future.

6 CONCLUSION

While generating the first set of subcomponents and categories for each of the components of the CAPE framework, we relied on prior research and deep experiences involved in K-12 CS education research, design, and implementation. As we continue our scoping review, we expect to investigate each article at the subcategory level, which will provide more granularity to categories such as *Affect* under student experiences. This will provide a clearer picture of areas that need more research. Furthermore, we will continue to compare the scholarship against the other data collected about each paper, while also cross-referencing these against measures of researching equity-focus. This will enable the broader research community to consider ways to cover gaps in available scholarship in the field of K-12 CS education research, including funding organizations that may understand the importance of having these areas explored given their known impact on academic achievement in other fields. By doing so, the corpus of research can become more complete in its coverage of all aspects of learning CS education among all students engaged (or who want to be engaged) in learning.

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