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An Extended Framework of Factors Across CAPE that Support K-12 Computer Science Education

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***Abstract*—Within K-12 computing education, the building blocks that contribute to student success and equitable outcomes are broadly captured in the CAPE framework (i.e., capacity, access, participation, experience). However, these broad components provide limited detail on the important factors that can support academic achievement, particularly within each component. Our research question for this study was: *What are factors comprising each component of CAPE that support academic achievement among K-12 CS students?*To answer this question, we first created an *a priori* set of factors based on previous research findings that have been found to contribute to academic achievement. After organizing these factors within each CAPE component, we conducted a systematic mapping review of K-12 CS education research (2019-2021) ($n = 196$) from publicly available peer-reviewed articles from the K-12 CS Education Research Resource Center. Through this mapping, we identified an additional set of factors that have been studied by CS education researchers and added these to our set of factors. More importantly, we found that capacity was the component investigated the most frequently and access was the least. There are many areas (or categories) within each component that remain unstudied (i.e., dual credit offerings, career guidance), even though they play a role in computing education. The expanded CAPE framework is now publicly available and can be used to inform researchers and practitioners about what each CAPE component comprises. These factors are accompanied by descriptions of each factor. Not only does it highlight the many factors to be considered when designing and delivering computing education to K-12 students, it also provides a solid framework for future research that synthesizes or analyzes homogeneous factors or explores how various factors may be correlated.**

***Index Terms*—Equity, K-12, primary, secondary, education research, CAPE, CAPE Framework, capacity, access, participation, experience**

I. Introduction

In recent years, the computing education research (CER) community has begun to shift its focus to equity concerns in primary and secondary (or K-12) computing education. This change coincides with the national CS for All movement announced by the White House administration in 2016 [1, 2]. However, many questions remain unanswered in the search for improved outcomes for all students learning CS. Computing educators and education researchers have increased awareness of the lack of access to and participation in CS education, as well as the inequitable outcomes of CS learning experiences across many student groups [3, 4]. Awareness of these issues has also increased internationally [5], and many are working to find practical and sustainable solutions for teaching CS to all students. Since the field of CS education is relatively new, the importance of research remains high, and building a strong foundation for CER is critical so that promising practices for teaching CS can be rapidly identified and adopted.

Unfortunately, CER publications on K-12 CS learning initiatives frequently miss the opportunity to report important details to contextualize and make possible the replication of work [6, 7, 8]. This lack is particularly problematic, as it is a new subject area in many grades, sharing knowledge about how to teach CS to diverse groups of learners in different contexts can immediately inform practices.

Fletcher and Warner designed the CAPE framework to understand an entity's contribution to building an equitable, outcome-driven education by examining it in terms of specific components [9]. This framework has also served as a disaggregation framework for understanding how to measure equitable outcomes among various groups of learners. The components of the framework are **capacity** for equitably offering CS education, equitable **access** to CS education through course offerings, equitable student **participation** in CS education, and equitable student **eperience** of CS education as identified by student outcomes [9] (see Figure 1). The framework is critical to supporting equity-focused research due to its careful consideration of the many aspects of education. It is also significant due to its support for computing education, which must be provided to ensure that all students are receiving impactful experiences and that outcomes are comparable between various population subgroups.

For this study, we sought to answer the research question:

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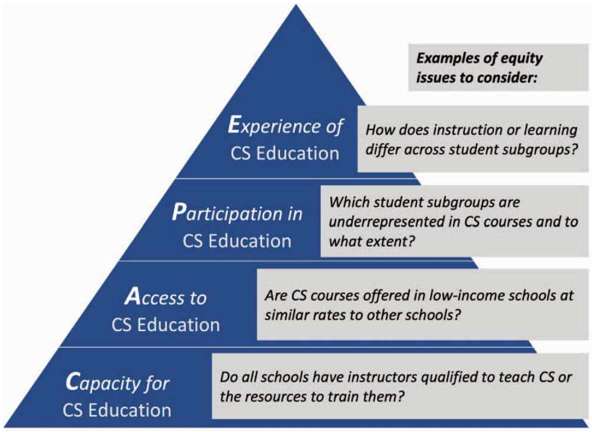

Fig. 1. CAPE Framework with examples [9]

What are factors comprising each component of CAPE that support academic achievement among K-12 CS students?

To answer this question, we conducted a systematic mapping review of K-12 CER publications (2019-21) using an *a priori* set of factors to identify aspects of the CAPE framework each publication addressed [10] , then categorized the publications according to the components of the *CAPE framework*. This study provides additional understanding of CAPE, highlighting the detailed factors that comprise each component. This study also offers important insights into research areas that may need more attention to identify promising practices that lead to addressing all students' learning needs.

II. Related Work

Mapping and gap analyses have previously been conducted on CER publications, including an analysis of topics studied [11] and reports on pre-college activities [12]. Szabo et al. found that most K-12 research is focused on programming language and environment or student engagement and motivation [13]. Many reviews of the CER literature have identified reporting gaps that prevent high-quality synthesis and meta-analysis [7]. In this section, we provide a synopsis of relevant literature related to equity-enabling research in K-12 CS education viewed through the CAPE framework.

A. Capacity

In 2018, Blikstein and Moghadam specifically highlighted 'implementation considerations' related to 'systemic obstacles' as key components of equitable CS education at scale [14]. Historically, marginalized populations face systemic barriers at the institutional level that affect their educational outcomes [15]. There is a small, but growing, literature on helping districts navigate the myriad of choices necessary to implement computing education equitably, create project goals, use instructional leadership strategies, identify relevant curriculum and learning pathways, create professional development plans, and secure the funds and resources necessary to implement these ideas [15]. District leaders have difficulty defining what counts as CS [16], stating what is going on in their own buildings [17], and conceptualizing how Broadening Participation in Computing and equity intersect with larger district plans [18].

B. Access

Access refers to students' access to courses, extracurricular activities, and state and national level exams. Equitable access refers to the offering of these courses equitably across various subgroups within and across schools and regions [19]. Dimensions of access include school contextual factors such as public or private status, Title I designation, urbanicity (rural, town, suburban, urban) and course admission policies (e.g. complete Algebra I, minimum GPA, class standing). For example, suburban schools are more likely to offer a CS course than other schools, e.g., 57% of suburban schools vs. 43% of rural schools [20]. Well-resourced schools are also more likely to provide CS learning opportunities for their students [21], including formal and informal learning activities. If a school does offer a CS course, there may not be enough sections or seats for all students who want to register, so the number of schools offering CS may not reflect access within the school to the course without studying why this phenomenon may be happening.

C. Participation

Participation refers to students' awareness and participation in courses, extracurricular activities, and national/state-level exams and is typically measured by enrollment or participation numbers. Equitable participation refers to the diversity of student enrollment in courses, extracurricular activities, and national-level exams that match the diversity of the schools. Participation has been studied and reported on by various researchers and organizations. Much research on the impact of CS learning experiences results in findings related to girls and historically underrepresented groups' participation in CS, such as 1) the impact of taking CS courses on CS attitudes [22], 2) taking the AP CS A exam [23], and 3) the impact taking a first course has on students enrolling in additional CS courses [24]. Generally, we know that research in high schools is more prevalent in the literature, capturing 39% of the publications since 2012, while middle schools represent 37% and K-5 captures only 24% [25]. In these articles, only 1.5% of the K-12 computing articles summarized at the K-12 Computing Education Research Resource Center include students with disabilities [25], which is significantly lower than the 2023 national average of 15% [26].

D. Experience

Measuring outcomes at the Experience component of the CAPE framework assumes that underrepresented students have access to and participate in CS courses and extracurricular activities. Equitable experience refers to cognitive and non-cognitive learning gains, as well as college and career interest and awareness, being equitable between student subgroups [9]. Experience considers outcomes of AP CS Principles courses to extracurricular activities such as robotics and cybersecurity. This includes the results of cognitive factors from students such as their knowledge of introductory CS and computational thinking [27]. Some noncognitive factors have also been investigated, including interest in computing, self-efficacy/confidence, attitudes, and relevance of computing in the lives of underrepresented students [22].

III. Research Methods

To answer our research question, *What are factors comprising each component of CAPE that support academic achievement among K-12 CS students?*, we performed a systematic mapping review [28] of relevant literature using a deductive coding technique. Four researchers involved in this work are experienced researchers with a deep understanding of the K-12 CS education ecosystem. One researcher is newer to CS education research, but also has research experience. The researchers are all women and bring with them an equity-focused lens and apply it to this work. This has resulted in the sharing of various factors that can influence the development of an education program that meets the needs of all students. These factors were examined in light of existing literature to determine how they were studied in all publications. A list of all factors is available at https://csedresearch.org/resources/extended-cape-codebook/.

A. Factor Book Creation

We first compiled an *a priori* set of factors based on previous research findings that identified factors that contribute to academic achievement [29, 30, 31, 25], including the CS Teachers Association K-12 CS Standards [32]. These included work from over 35 factors identified by Farrington et al. [29] and more than 20 factors from Lee and Shute[33]. We grouped these factors into capacity (69 factors), access (12 factors), participation (4 factors), and experience (84 factors).

As we collaboratively classified each identified factor during our review, we saw a need to further organize all these factors, similar to how Hattie and Yates have created various categories to group similar factors that influence academic achievement [34]. Within each component, we formed *subcomponents*. For example, the Capacity component has eight subcomponents: Community Environment, Community Culture, and Ideology; Funding; Human Resources; Curriculum; Policies; Standards; School Environment, School Culture, & Ideology; and Pedagogy.

Subcomponents are further subdivided into *Categories*. For example, the *Policies* subcomponent in Capacity currently includes the following categories: Accountability, Core graduation requirements, Dual credit offerings, Funding, Higher education admission requirements, Required number of course offerings, CS pathways, and Teacher-related. Categories are subdivided into subcategories *Subcategories*. For example, the Teacher-related category includes the subcategories Credentials, Microcredentials, and Certifications.

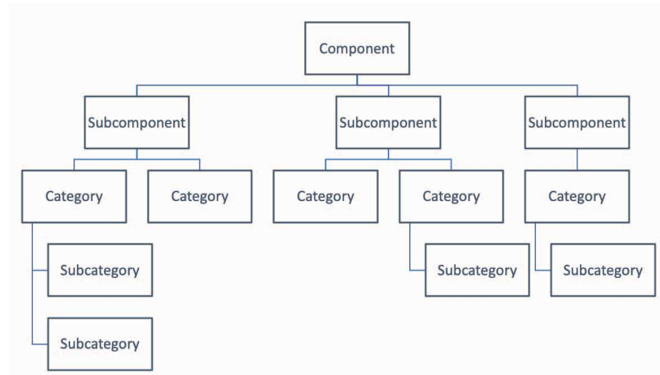

Fig. 2. Hierarchy of components, subcomponents, categories, and subcategories in the book of factors.

B. Systematic Mapping Review

We conducted a systematic mapping review for this study. A systematic mapping review is defined as a systematic review that "maps out and categorizes existing literature from which to commission further reviews and/or primary research by identifying gaps in research literature." [28, p. 26] For our study, we used the adapted SALSA methodology [28] PSALSAR [35]. PSALSAR includes the following steps:

- Step 1: Protocol - Define the study's scope and search, including creating a framing question and defining the datasets and the inclusion/exclusion criteria.
- Step 2: Search - Search for studies that meet criteria.
- Step 3: Appraisal - Review quality of the dataset (papers).
- Step 4: Synthesis - Categorize and analyze data.
- Step 5: Analysis - Analyze results and share work.
- Step 6: Report - Publish the report.

1) Steps 1 and 2: Protocol and Search: We chose to center our work on three years of recent K-12 CS education research publications (2019-2021) ($n = 196$) from publicly available data from the K-12 CS Education Research Resource Center [25]. The curation process for the Resource Center includes organizing, evaluating, and parsing articles and papers to determine if an article meets the predefined criteria:

- Describe or evaluate a computing activity or process,
- Target K-12 participants (students or teachers) and,
- Designed to teach computing or computational thinking.

Each article was analyzed to identify its primary research questions, data collected as part of the study, activities that were evaluated, and more [36]. The articles are selected from 12 journals and conference publishing venues (2012-2022) [1].

[1]ACM International Computing Education Research (ICER), ACM Innovation and Technology in Computer Science Education (ITiCSE), ACM SIGCSE Technical Symposium on Computer Science Education (SIGCSE TS), ACM Transactions on Computing Education (ToCE), Frontiers in Education (FIE), IEEE Global Engineering Education Conference (EduCon), IEEE Research in Equity and Sustained Participation in Engineering, Computing, and Technology (RESPECT), IEEE Transactions on Education (ToE), Journal of Educational Computing Research (JECR), Koli Calling (Koli), Taylor & Francis Computer Science Education (CSE), and Workshop in Primary and Secondary Computing Education (WIPSCE).

2) Step 3: Appraisal: We chose to leverage an existing dataset that had previously been appraised for quality and relevancy [25]. Therefore, we focused on performing another review of each article as we read it to ensure that it met the criteria. It was also at this step that we removed articles that were literature reviews, since we were concerned about double-counting of research focus areas for papers that may have been in our dataset that were also included in the literature reviews.

3) Step 4: Synthesis: Adapting the Framework Method for coding [37], we adopted the following process:

1) We established a norm setting where four researchers identified factors for the first two publications together using the *a priori* book of factors and the Quirkos qualitative analysis tool [38].
2) Two researchers were assigned to identify factors in an additional 16 articles using the book of factors, and two other researchers were assigned to a different set of 16 articles. The researchers independently identified the factors in their assigned articles.
3) After independently identifying the factors, the researchers met to discuss anomalies among the 32 publications until a consensus was reached on each [39].
4) Steps 2 and 3 were repeated until the coding was complete. Throughout this process, we discussed and resolved the discrepancies intermittently.

We reviewed $n = 82$ (2019), $n = 113$ (2020) and $n = 151$ (2021) articles, for a total of $n = 346$ articles. Through this mapping review, we discovered additional factors ($n = 129$) that we added to our book of factors.

IV. Step 5: Analysis

As described in Section III-A, we initially seeded our set of factors with known factors that support student academic achievement. In this section, we present the results of our analysis across each CAPE component.

A. Capacity

Systemic barriers to K-12 CS education need to be addressed at the capacity level [14]. Although the Capacity component has the highest number of CAPE factors that have been investigated ($n = 305$) (see Table I), Capacity also has the highest number of categories that remain to be investigated. Hattie and Yates's previous findings indicate that the collective teacher self-efficacy (in a school) is one of the strongest factors that influence academic achievement among students ($d = 1.57$). Programs that leverage Piagetian methods ($d = 1.28$), instructional scaffolding ($d = 0.82$), and school climate ($d = 0.32$) also support academic achievement.

In total, there are eight subcomponents and 43 categories. Pedagogy ($n = 194$) and Curriculum ($n = 144$) were the topics studied the most frequently in our data set. The least studied were Funding ($n = 2$) and Standards ($n = 9$). Capacity also contains the most frequent category investigated within our set of publications ($n = 180$) when compared against all of the categories across all of the components: **Capacity** → *Pedagogy* → Student-centered. The second most investigated category ($n = 85$) was **Capacity** → *School Environment, Culture, & Inclusion* → Teacher.

TABLE I
Counts of papers investigating factors across Capacity categories. CEC&I = Community Environment, Culture, & Ideology. SEC&I = School Environment, Culture, & Ideology.

Subcomponent	Category	Count
CEC&I	Families	8
	COVID-19 Pandemic	4
	Extracurricular Providers	1
	Media	0
	Stakeholders	0
	Student Influences	0
Curriculum	Resource materials & facilities for teaching CS	64
	CS curriculum	38
	Assessments	27
	CT Curriculum	15
	Course Descriptions	0
	Prerequisites	0
Funding	Origination	2
	Type	0
Human Resources	Teachers	63
	Professional Development	51
	Professional Learning Networks/Communities	2
	Teachers - Special Education	1
	Administrators	0
	Guidance counselors	0
	Instructional supervision	0
	Library/Media specialist	0
Pedagogy	Student-centered	180
	Teacher-centered	14
Policies	Pathways	5
	Required # of course offerings	2
	Teacher	2
	Core graduation requirements	1
	Higher ed admission requirements	1
	Dual credit offerings	0
SEC&I	Teacher	85
	Inclusive and Equitable Classroom Cultures	61
	Student Voice, Agency, and Self-Determination	6
	Power dynamics	4
	Administrators	3
	Racism in CS and Anti-Racist Practices	3
	Guidance Counselors	2
	Academic Emphasis	1
	Sexism in CS and Anti-Sexist Practices	1
	Belongingness	0
	Career Guidance	0
	Classroom behaviors	0
	Diverse Professionals and Role Models	0
	Family and Community Culture	0
	Pedagogy and Curriculum are Rigorous	0
	Title I Status/Socio-economic status	0
Standards	CSTA K-12 Standards	4
	State-created Standards	4
	ISTE Standards	1
	Other	0

B. Access

The next component, **Access**, has the fewest associated factors that have been investigated ($n = 46$) (Table II). Access can be difficult to measure, since many states are still forming standards, creating course descriptions, and determining how to count who has access to what learning content in CS. As these data grow, more research can consider how capacity is related to access and how access is related to participation.

TABLE II
PAPERS INVESTIGATING FACTORS ACROSS ACCESS CATEGORIES.

Subcomponent	Category	Count
Community-based activities	Fees	1
	Scheduling	1
	Transportation to Activity	1
	Types	1
	Availability	0
	Prerequisite requirements	0
	Safety	0
Curriculum offerings	Integrated CS	23
	Types	21
	Course Availability	2
	Course Fees	0
	Course Prerequisites	0
	Course Scheduling	0
School-based extracurricular activities	Availability	1
	Fees	0
	Prerequisite requirements	0
	Safety	0
	Scheduling	0
	Types	0

The most investigated **Access** subcomponent is *Curriculum offerings (Access)* ($n = 46$), followed by *Community-based activities (Access)* ($n = 4$). The most frequent **Access** category investigated in our study was *Curriculum offerings* $\rightarrow$ Integrated CS ($n = 23$), followed by *Curriculum offerings* $\rightarrow$ Types ($n = 21$). However, each of the **Access** subcomponents has categories not found in the publications we analyzed. This includes *Community-based activities* $\rightarrow$ Availability, *Curriculum offerings* $\rightarrow$ Course fees, and *School-based extracurricular activities* $\rightarrow$ Scheduling. Finally, the least investigated subcomponent was *School-based extracurricular activities* ($n = 1$). Given the importance of extracurricular activities to student learning [40, 41], conducting research on access may provide insight into how to increase CS learning experiences in communities.

C. Participation

The **Participation** subcomponent is the second least investigated component ($n = 52$) (see Table III). Similar to access, the lack of publications investigating participation in CS was surprising. Again, we may be able to attribute this to the fact that data collection across all US states is still in the process of formation. The enrollment counts of the students (which reflect participation) are reported in the annual Code.org, CSTA, & ECEP Alliance State of CS Education report [20]; however, these data have limits due to the difficulty in collecting data within each state and district, particularly in grades K-8.

The subcomponents with the highest number of publications are *Community-based extracurricular activities (Participation)* ($n = 30$) and *Course enrollment (Participation)* ($n = 17$). The least investigated subcomponent is *School-based extracurricular activities (Participation)* ($n = 11$).

The most investigated **Participation** category from our subset of publications is *Course enrollment (Participation)* $\rightarrow$ Enrollment in CS Principles courses ($n = 6$). Although *Community-based extracurricular activities (Participation)* has the highest count, this subcomponent does not have any

TABLE III
COUNTS OF PAPERS INVESTIGATING PARTICIPATION-RELATED FACTORS.

Subcomponent	Category	Count
Community-based extracurricular activities		30
Course enrollment	CS Principles courses	6
	CS A courses	4
	Other CS Courses	3
	Foundations	3
	Integrated CS	1
School-based extracurricular activities		11

categories. Conversely, the category with the lowest count is *Course enrollment (Participation)* $\rightarrow$ Integrated CS ($n = 1$).

The relationship between access and participation remains an area ripe for study, particularly in states that require CS to be taught but do not require all students to learn it. For those interested in broadening participation in computing, research that investigates these and other relationships can provide key insight into visible and hidden barriers to participation.

D. Experience

The **Experience** component has the second highest number of associated factors that have been investigated ($n = 258$) (see Table IV). **Experience** has a total of four subcomponents. The subcomponent with the highest number of publications is *Student Engagement* ($n = 321$), followed by *Content Knowledge* ($n = 201$) and*learning strategies* ($n = 51$). Although student engagement (affect and cognition) was the most investigated area, further research is needed in behavior, as behavioral strategies have been positively correlated with academic achievement (e.g., test-taking strategies, note-taking skills, help-seeking [33]).

TABLE IV
COUNTS OF PAPERS INVESTIGATING EXPERIENCE-RELATED FACTORS.

Subcomponent	Category	Count
Content Knowledge	Algorithms and Programming	119
	Abstraction	28
	Computing Systems	17
	Data and Analysis	13
	Other	10
	Networks and the Internet	8
	Impacts of Computing	3
	Privacy and Security	2
	Human-Computer Interaction	1
	Communication and Coordination	0
	System Relationships	0
Learning Strategies	Meta-Cognitive	45
	Behavioral	7
	Other	0
Social-Familial Influences	Parental/Guardian Involvement	11
	Peer Influences	1
	Technology access	1
Student Engagement	Affect	134
	Cognition	127
	Behavior	60
	Other	0

The categories in the Content Knowledge subcomponent were derived from the widely used CSTA K-12 CS standards

[32] and many areas remain under investigated. There is an opportunity to expand research in these areas to better understand how students learn these topics. In particular, two Content Knowledge categories that were not investigated in any of the publications in our subset: *Content Knowledge* → Communication and Coordination and *Content Knowledge* → System Relationships. Finally, the subcomponent with the lowest count of publications from our subset is *Social-Familial Influences* ($n = 13$).

E. Limitations

Given the enormity of this process and what we could capture at this initial research stage, there are certainly limits to our findings. The set of publications used in this analysis was limited to three years and to 12 publication venues. Extending these parameters would provide additional data from the publication corpus, providing us with more details about the work. Additionally, with any quantitative data, there is always the risk of reducing the complexity of a study to numbers. For example, just because a factor is only investigated in five previous research studies, does this mean that it is understudied? Or does it perhaps mean that it is perhaps *over investigated* when compared to other areas, particularly in this early stage of evidence discovery in K-12 CS education?

V. Conclusion and Future Work

This study is a stepping stone to understanding research gaps that need further investigation, particularly in the context of promising practices for all children. The expanded CAPE framework can be used to inform researchers and practitioners about what each CAPE component comprises. This book of factors is accompanied by descriptions of each factor. Not only does it surface the many factors to be considered when designing and delivering high-quality CS education to K-12 students and teachers, it also provides a solid framework for future research that synthesizes or analyzes homogeneous factors, as well as how various factors may be correlated.

Acknowledgment

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