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The Landscape of State and National K-12 Computer Science Learning Standards (Fundamental)

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Abstract

Introduction: Learning standards are a crucial determinant of computer science (CS) education at the K-12 level, but they are not often researched despite their importance. We sought to address this gap with a mixed-methods study examining state and national K-12 CS standards in the U.S.

Research Question: What are the similarities and differences between state and national computer science standards in the U.S.?

Methods: We tagged the state CS standards ($n = 9695$) according to their grade band/level, topic, course, and similarity to a Computer Science Teachers Association (CSTA) standard. We also analyzed the content of standards similar to CSTA standards to determine their topics, cognitive complexity, and other features.

Results: We found some commonalities amidst broader diversity in approaches to organization and content across the states, relative to the CSTA standards. The content analysis showed that a common difference between state and CSTA standards is that the state standards tend to include concrete examples. We also found differences across states in how similar their standards are to CSTA standards, as well as differences in how cognitively complex the standards are.

Discussion: Standards writers face many tensions and trade-offs, and this analysis shows how – in general terms – various states have chosen to manage those trade-offs in writing standards. For example, adding examples can improve clarity and specificity, but perhaps at the cost of brevity and longevity. A better understanding of the landscape of state standards can assist future standards writers, curriculum developers, and researchers in their work.

1 Introduction and Background

There are 42 U.S. states with computer science standards, totaling just under 10k standards across all grade levels K-12. These standards form a nexus at the intersection of policy, curriculum, instruction, and research and therefore have an enormous impact on how computer science (CS) education is experienced by K-12 students. As a consequence, understanding the landscape of these standards is a crucial precursor to making sense of and improving CS education in the US.

While there have been studies of engineering education standards more broadly [1–3], research focused more specifically on computer science learning standards is much less common. A 2010 report from the Association for Computing Machinery and CSTA explored whether and how CS was included in state standards [4]. This work found that the US was not adequately preparing students for a society where technology was involved in nearly every facet of life, to the extent that there had actually been a decline in the number of high school CS courses and that only 14 states had high school CS standards. They recommended that the states articulate CS education with more clarity. Early adopters of state standards may have based their standards on earlier iterations of the CSTA standards.

Pokorny compared a previous iteration (from 2011) of the CSTA standards to other technology and math standards, finding that there was not extensive overlap between these CSTA standards and the technology standards, but that the CSTA standards complemented the math standards [5]. Similarly, Love and Strimel compared CS concepts with the International Technology and Engineering Educators Association Standards for Technological Literacy, finding that there was some overlap in concepts [6]. Guo and Ottenbreit-Leftwich explored state CS standards via a content analysis [7]. Their analysis found that many states followed CSTA's lead in organizing standards, but that there were some significant divergences, especially in terms of where within the overall curriculum CS was housed (e.g., in career and technical education) and what topics were added (e.g., digital literacy). Oda et al. conducted an international comparison of CS instruction in ten countries by performing a content analysis on national curricula documents; they found that, for the countries they studied, most initially focus on instruction related to impacts of computing, programming, and algorithms and then, in subsequent grades, expand instruction to topics related to additional topics such as cybersecurity, hardware, and software [8].

This paper builds upon this prior work by comparing state and CSTA CS standards in the U.S., which has not heretofore been done at scale. This study explores the research question: What are the similarities and differences between state and national computer science standards in the U.S.?

2 Methods

The dataset used in this paper contained the current CSTA standards, published in 2017 ($n = 120$) as well as standards from the states, published between 2016 and 2023 ($n = 9695$). We did not include in our dataset state standards that were labeled "continued growth" (such as North Dakota 7.HA.2), or "continuation of this standard is not specifically included or excluded" (such as South Carolina HS3.DA.1.3) or used similar phrases. We also did not include any supporting materials (e.g., the descriptive statements accompanying each CSTA standard that often provide clarification and examples). We also excluded career and technical education (CTE) standards unless they were the only CS standards for a state (see [7]).

The states assign their standards to grade bands and/or grade levels. We classified each state standard according to its state-assigned grade band or grade level. Additionally, we assigned each standard to a uniform set of grade bands (i.e., K-2, 3rd-5th, 6th-8th, 9th-12th); note that our band assignments did not necessarily match the state's assignment (e.g., some states used 9th-10th and 11th-12th bands or grade levels). We also tracked whether each standard was assigned to a course and/or to a category. We also noted whether each standard was (1) entirely different from, (2) loosely similar to, (3) very similar to, or (4) identical to a CSTA standard. For all but the 'different' category, we noted to which CSTA standard(s) the state standard was similar. We then mapped these categories to a score, so that 'different' standards were assigned 1.0, identical

Similarity Level	Score
Identical	4.0
Very similar	3.0
Loosely similar	2.0
Different	1.0

Table 1: Each state standard was tagged according to its similarity to a CSTA standard. This table shows the numeric scores that were then mapped to the similarity tags to enable the data analysis.

standards were assigned 4.0, and so forth (see Table 1).

We also performed a content analysis on the standards that were very similar to or loosely similar to on a CSTA standard to examine in what ways they differed from the CSTA standard. We also assigned each standard to a level of Bloom's Taxonomy (using the first verb if there was more than one) using *Bloom's for Computing: Enhancing Bloom's Revised Taxonomy with Verbs for Computing Disciplines* [9] and similar verb lists as needed.

3 Results

3.1 Count and Organization of State Standards

Of the 42 states in our dataset, the average state had 231 standards, ranging from a high of 1,436 in Arkansas (due to its numerous courses, each with its own standards) to a low of 83 in Colorado (which only has one set of standards, at the 9th-12th level). All states use a system of grade levels (e.g., 1st, 2nd, 3rd) and/or grade bands (e.g., K-2nd) to organize their standards. Organizational systems vary, with common patterns including (1) grade level standards for K-8th and one grade band for 9th-12th and (2) bands for K-2nd, 3rd-5th, 6th-8th, 9th-10th, and 11th-12th (which is the system CSTA used in its 2017 standards).

CSTA organized its 2017 standards into concept groups based on the K-12 CS Framework [10]: (1) Computing Systems, (2) Networks and the Internet (3) Data and Analysis, (4) Algorithms and Programming, (5) Impacts of Computing. Almost all states use a concept group system, directly adopting CSTA's groups, adjusting them, or creating their own. For example, Computational Thinking was added to Utah's groups, and some states add Digital Citizenship. A small number of states organize their standards into courses; most often, this is at the high school level. As an example, West Virginia offers Computer Science & Mathematics and Introduction to Geographic Information Systems, among other courses.

3.2 Similarity of State and CSTA Standards

We assigned similarity scores to each standard based on its similarity to a CSTA standard, and then we averaged these scores by state. As Figure 1 shows, average similarity ranged from a low of under 1.3 (for Texas and Georgia) to a high of 4.0 (for New Mexico, New Hampshire, Michigan, Hawaii, and Iowa); the average state similarity score was 2.5. We tested whether the similarity scores would be substantially different if the standards were separated into two groups, K-8th and 9th-12th, but they were not. Similarly, there was virtually no correlation between the year a state adopted its standards and its average similarity.

The average state includes 96% of the CSTA subpractices (e.g., subpractice 2.1 Cultivate working relationships is a subpractice of 2: Collaborating around computing). Very few states do not

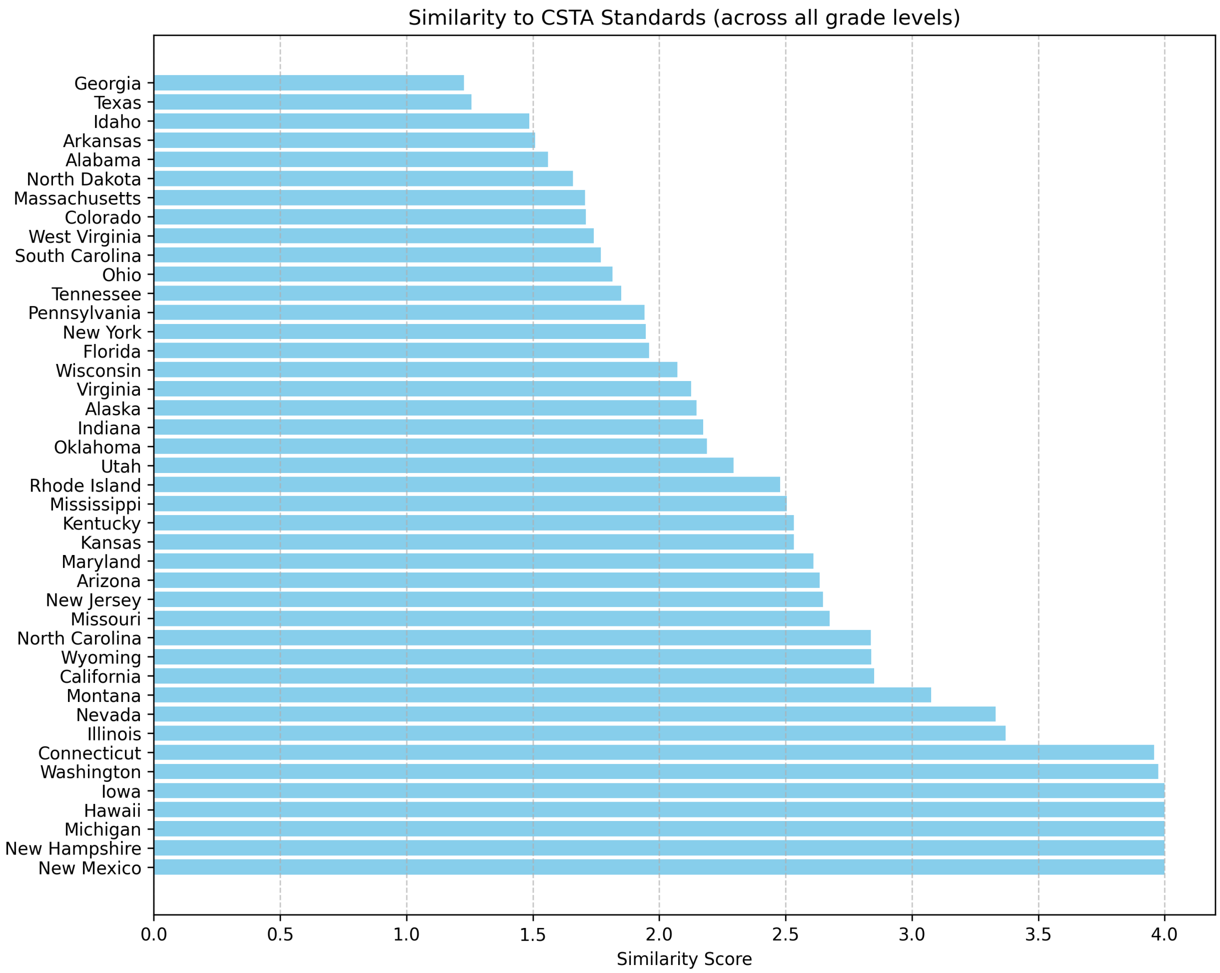

Figure 1: Average similarity to CSTA standards by state. To calculate the similarity score, each state standard was labelled as identical to, very similar to, loosely similar to, or different than a CSTA standard, and then numeric scores were assigned (see Table 1). These scores were averaged on a per-state basis to yield the values in this chart.

include one or more of the subconcepts at any level; on average, a state has 97% of the subconcepts (e.g., variables, control, and modularity are subconcepts of Algorithms and Programming).

3.3 Analysis by CSTA Standard

We calculated how many state standards are very or loosely similar to each CSTA standard. The overall average was 1.72, with a high of 3.9 and a low of 1. Our content analysis identified that the most common difference between a CSTA standard and the state standards that were very or loosely similar to it was that the state standards added examples to the CSTA standards. For example, Table 2 shows some of the state standards that are very or loosely similar to CSTA 1B-NI-05, a 3rd-5th grade standard about cybersecurity. This example shows how standards add concrete examples – hacking, passwords, phishing, etc. – to the CSTA standard, which mentions cybersecurity problems more generally without providing examples.

Table 2: An example of standards that are very or loosely similar to a CSTA standard that have added examples (the examples are in italics)

Standard	Text
CSTA 1B-NI-05	Discuss real-world cybersecurity problems and how personal information can be protected.
North Dakota 5.SE.1	Recognize that there are real-world cybersecurity problems *(i.e., hacking)* when interacting online.
Arkansas CSK8.G5.4.1	Identify real-world cybersecurity problems *(e.g., malicious hacking)* and apply strategies for protecting and securing personal digital information.
Maryland 5.NI.C.02	Discuss real-world cybersecurity problems and explain how personal information can be protected *(e.g., antivirus software, backing up data, strong passwords)*.
Massachusetts 3-5.CAS.a	Describe the threats to safe and efficient use of devices *(e.g., SPAM, spyware, phishing, viruses)* associated with various forms of technology use (e.g., downloading and executing software programs, following hyperlinks, opening files).

The average CSTA standard has an identical, very similar, or loosely similar standard in 77% of states. Table 3 shows the most and least often paralleled CSTA standards, per the percentage of states (with CS standards) that have a standard that is identical to or similar to each CSTA standard. The CSTA standard that is most often paralleled in the state standards is 1B-IC-18 ("Discuss computing technologies that have changed the world, and express how those technologies influence, and are influenced by, cultural practices" [11]), a 3rd - 5th grade standard that has a parallel in 98% of states. The least paralleled is 3B-AP-09 ("Implement an artificial intelligence algorithm to play a game against a human opponent or solve a problem" [11]), an 11th - 12th grade standard that is only paralleled in 48% of states.

Table 3: CSTA standards that are most and least paralleled in the state standards

Standard	Grade Band	Topic	% of States w/Parallel Standards
1B-IC-18	3rd - 5th	important computing technologies	98%
2-AP-12	6th - 8th	programs with control structures	95%
2-IC-20	6th - 8th	tradeoffs in technologies	95%
3A-IC-24	9th - 10th	impacts of computing	95%
1A-AP-08	K - 2nd	algorithms of daily events	93%
3A-AP-20	9th - 10th	software licenses	60%
1A-AP-15	K - 2nd	program development process	57%
3B-IC-25	11th - 12th	benefits and harms of artifacts	55%
3B-AP-19	11th - 12th	multi-platform programs	55%
3B-AP-09	11th - 12th	AI algorithms	48%

Table 4: States with the highest counts of standards that differ from CSTA standards

State	Count
Arkansas	727
Texas	643
Georgia	229
Alabama	161
Ohio	145

3.4 State Standards Different from CSTA Standards

Table 4 shows the five states with the highest count of standards that differ from the CSTA standards. Arkansas' high count is attributable to the fact that it organizes standards by course and offers many different, often specialized, CS courses.

Almost one-third of the state standards were classified as different from (that is, not even loosely similar to) the CSTA standards. We explored various features of this group of 'different' standards. Table 5 shows the categories of these standards, according to the categories assigned by each state.

Table 5: Most Common Categories for State Standards Classified as Different from CSTA Standards

Category	K-2nd	3rd-5th	6th-8th	9th-12th
Impacts of Computing	31	46	57	205
Computers and Communications	13	16	19	125
Computational Thinking and Problem Solving	0	0	27	145
Algorithms & Programming	0	0	0	122
Data, Information, and Security	0	11	11	126
Artificial Intelligence	21	26	32	22
Computing Systems	27	18	20	40
Networks & the Internet	16	15	0	0
Data & Analysis	0	12	16	12
Digital Literacy	18	25	17	0
Employability skills	0	0	0	32
Technology & Engineering	13	0	0	0

Figure 2 compares the percent of all state standards and the percent of 'different' standards at each level of Bloom's Revised Taxonomy.

Table 6 lists the most common verbs in the different standards.

4 Discussion

The results section provides an overview of the landscape of state and national (CSTA) CS standards in the U.S., as well as some analysis of the relationship between the various state standards and the CSTA standards. In this section, we discuss the major themes identified, as well as exploring the tensions that these themes raise for standards writers.

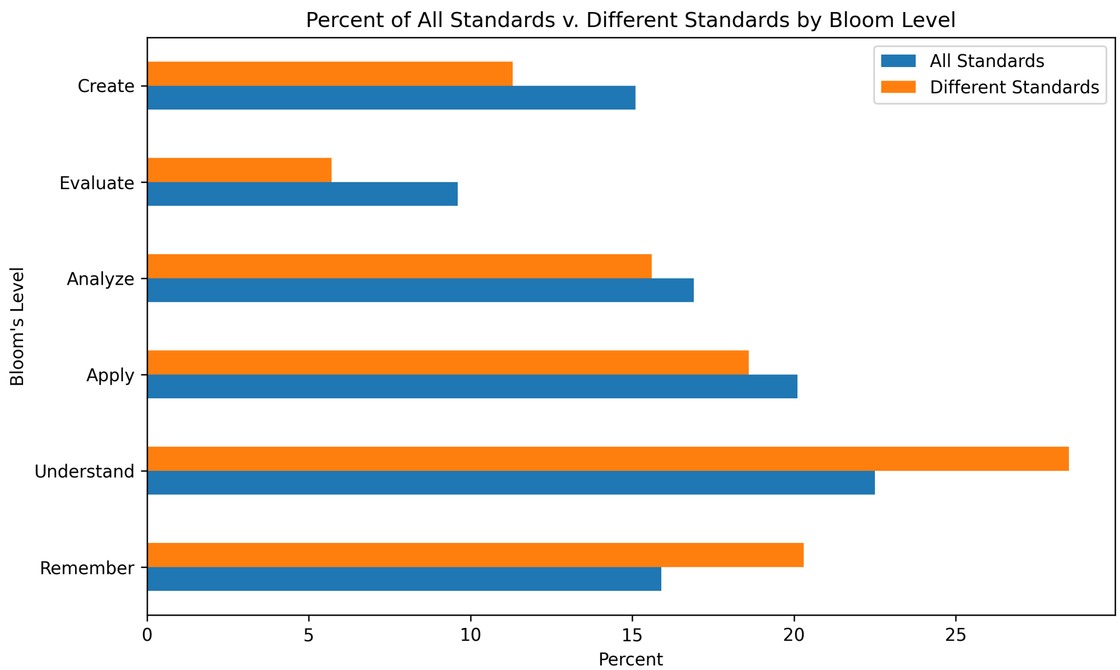

Figure 2: Bloom's level of all state standards and state standards classified as different from CSTA standards

Table 6: Most common verbs in standards categorized as different from CSTA standards

Verb	**Count**
Identify	357
Demonstrate	218
Describe	183
Create	177
Explain	174
Use	146
Compare	128

First, there is broad similarity between most states' standards and the CSTA standards in terms of their organizational structure, which confirms the findings of Guo and Ottenbreit-Leftwich [7]. All standards in this data set were organized chronologically, either by grade level or grade band. And, all standards were organized into groups by topic or content. Within that broad similarity, however, some states were far more similar to the CSTA standards in their organizational structure than others, with various schemes used to group grade levels into bands and various topics chosen. Some of these differences may result from instruction to state standards writers to personalize the CSTA standards for their state and to avoid directly adopting them.

A few states also organize their standards into distinct courses. The states differed in the overall similarity of their standards' content to the CSTA standards, with some states having identical standards and others being quite different, yielding a diverse landscape of CS standards across the nation. Choosing an organizational structure and content that matches what is most commonly used – by other states and by CSTA – may make it easier for states to adopt instructional materials that are already widely available. However, a more customized but less popular organizational system may better reflect local conditions and priorities. Furthermore, matching the structure of other disciplinary standards in the state may facilitate easier implementation and support greater interdisciplinary instruction.

Second, the state standards that differ from the CSTA standards tend to be at a lower level of cognitive complexity (i.e., a lower level of Bloom's taxonomy) than the state standards overall. This is seen in Figure 2, which shows that the 'different' standards are concentrated at the *understand* and at the *remember* levels of the taxonomy. And, the most common verbs in the 'different' standards (as shown in Table 6) are *identify*, *demonstrate*, and *describe* – all of which are at the lowest two Bloom's levels. Thus, it seems to be the case that the different standards emphasize lower-order thinking skills.

It is perhaps surprising given the recent expansion of AI technologies that the *least* paralleled CSTA standard concerns the implementation of AI algorithms. However, that expansion is so recent – largely stemming from the November 2022 introduction of ChatGPT – that it has not yet had an impact on learning standards at scale. We anticipate that future iterations of state and CSTA standards will probably focus more on AI. Many states adopted their standards between 2016 and 2022 – a narrow window in itself, with significant policy implications.

Third, the most frequent difference between the state standards that are very or loosely similar to a CSTA standard is that the states tend to add examples to the CSTA standard, as shown in Table 2. Again, this presents a tension for standards writers: omitting examples may result in a lack of clarity on what, precisely, a standard should cover and at what depth and granularity. However, including examples may lead to too much of a focus on implementation details and not on general principles; it may also result in standards that are more quickly out of date due to changes in technology. One way to address this tension is to include examples in supplemental materials related to the standards.

We attempted to be consistent across standards and across reviewers, but one limitation of this work is that the process for categorizing each state standard's similarity to a CSTA standard (i.e., very similar to, loosely similar to, etc.) is somewhat subjective. Additionally, comparing standards across states can be difficult due to differences such as whether some standards are embedded within particular courses (such as cybersecurity, which might only be taken by very few students) or a basic CS course (which may in fact be a graduation requirement). Additionally, comparing standards across states can be difficult due to differences such as whether some standards are embedded within particular courses (such as cybersecurity, which might only be taken by very few students) or a basic CS course (which may in fact be a graduation requirement). Further, we are unaware of any national data that assesses to what extent standards that are *adopted* are actually *taught*.

5 Conclusion

The 2010 report on CS education from the ACM and CSTA called for more states to articulate CS education standards [4]. That has happened, although perhaps not with the clarity and unity called for in that report. Instead, the 42 states in the U.S. that now have CS standards present a mosaic of similarity to and difference from the current CSTA standards, which may represent adoption to local contexts but may also complicate aspects of CS education ranging from teacher PD to alignment with post-secondary courses. We identified several tensions related to the task of crafting CS standards.

Awareness of these tensions and the ways that various states have negotiated them will be useful to those whose work is related to CS learning standards, including future standards writers as well as curriculum developers and CS education researchers, among others, as the first systematic study of state CS standards. We have made the script that we used for analyzing the cognitive complexity of standards available (tinyurl.com/2ermdxhv) as well as our report that geared toward standards writers that presents our findings at greater length (tinyurl.com/56vm8pps, including briefs for each CSTA standards and for each state that has standards. This tool may be used to understand the Bloom's level of proposed standards individually or as a group. We hope that this tool as well as this landscape will contribute to future efforts that enhance computer science education for K-12 students.

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