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Comparing Learning Taxonomies with Computer Science K-12 Standards

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Abstract

There is a need to analyze state computer science standards to determine their cognitive complexity and alignment across grades. However, due to the recency of these standards, there is very little research on the topic, including the use of various educational taxonomies as analysis tools. The purpose of this paper is to answer the question, How do Bloom's Revised and the SOLO taxonomies compare in their analysis of computer science standards? We categorized state CS standards according to their level in Bloom's Revised Taxonomy and the SOLO taxonomy. Analyzing state CS standards using the Bloom's or using the SOLO taxonomy produces wide areas of agreement but also some differences that might be important in various use cases, such as aligning standards across grade levels or determining whether a standard addresses a higher-order thinking skill.

Introduction

State learning standards are relatively new for CS education at the K-12 level: in 2017, just six states had K-12 CS standards, but as of 2023, 41 states did (CSTA et al., 2024). Standards can play a prime role in shaping students' CS experience based on the influence that standards normally have over curriculum development, professional development, and student assessment.

Due to the recency of the K-12 CS expansion, there is very little research on the states' CS standards, including their cognitive complexity and alignment across grade levels. More research may prove a useful first step in gaining insight into how to craft standards that optimally lay the groundwork for creating equitable CS experiences that are of high quality. In turn, gaining a better understanding of the strengths, weaknesses, and outcomes of various approaches to the analysis of state standards will enable better analysis of state standards. Thus, this paper seeks to answer the question, How do Bloom's Revised and the SOLO taxonomies compare in their analysis of computer science standards?

Background

One way to analyze educational materials – including state standards, course learning objectives, and student assessments – is through a learning taxonomy. There is no shortage of learning taxonomies, including Bloom's, Marzano's, SOLO, Webb's, Fink's, and Shulman's.

Of all of the educational taxonomies, Bloom's is the most widely known (Irvine, 2021). It was initially developed in the 1950s (Bloom, 1956) with the goal of classifying assessment tasks. It was revised in 2001 (Krathwohl & Bloom, 2001), with an expanded goal of addressing teaching and learning as well as assessment (Irvine, 2021). Bloom's revised taxonomy (hereafter Bloom's) features six levels, ranging from the least to the greatest cognitive complexity. These levels are *remember*, *understand*, *apply*, *analyze*, *evaluate*, and *create*.

Another common taxonomy, the Structure of the Observed Learning Outcome (SOLO), was developed in the early 1980s (Biggs & Collis, 1982). SOLO's five levels are organized according to how the student treats details: *pre-structural* (irrelevant material), *uni-structural* (one set of relevant details), *multi-structural* (several sets of details), *relational* (integrated sets of details), and *extended abstract* (integrated sets of details are abstracted).

Taxonomies of learning – and Bloom's in particular – have been subject to criticism for promoting a hierarchical, inappropriately quantified, homogenized, and conformist view of learning (Doughty, 2006). And both Bloom's and SOLO have been found to harbor some ambiguity (Stanny, 2016; Wells, 2015) regarding classification of tasks. Nonetheless, learning taxonomies may be a productive analytical tool for designing and evaluating educational materials. And because some learning taxonomies – including Bloom's and SOLO – can be applied programatically to very large data sets, they can be essential for analyzing content at scale.

This study compares Bloom's with the SOLO taxonomy since the other taxonomies are either not as widely used and/or do not lend themselves to the analysis of a very large dataset. (For example, identifying the main verb of a course objective will normally be sufficient to assign that objective to a level of Bloom's taxonomy, but that same objective might be assigned to any level of Webb's Depth of Knowledge, depending on how complex the student response is expected to be (Irvine, 2021).)

There is only a modest amount of prior research analyzing learning standards using different educational taxonomies. For example, the cognitive complexity of the Common Core Standards was determined to be lower than the New Jersey standards for English Language Arts according to Webb's Depth of Knowledge (Kim et al., 2015). Music standards were analyzed with Bloom's and Webb's, finding that these learning taxonomies did not always map well to the domain of music education (Branscome & Robinson, 2021).

There is also very little previous research empirically comparing learning taxonomies. One study compared Bloom's, SOLO, and a domain-specific scale in their assessment of case-based learning scenarios in medical education, finding that SOLO's assessment was most similar to an expert instructor's (Koskinen, 2007). Another study analyzed seventh grade social studies assessments via SOLO and Bloom's, finding that SOLO was a more reliable taxonomy for determining the cognitive complexity of a task (İlhan & Gezer, 2017).

Given the overall paucity of research examining learning standards via educational taxonomies and given the relative recency of K-12 CS education at scale, it is no surprise that there is very little research applying taxonomies to CS learning standards. However, related efforts include proposals to develop CS-specific (Fuller et al., 2007) and cyber-security-specific (Harris, 2015) taxonomies and to apply Bloom's specifically to CS (ACM Committee for Computing Education in Community Colleges, 2023) by assigning CS-specific verbs (e.g., *debug, optimize*) to the appropriate Bloom's level. The SOLO taxonomy has also been applied to CS education, showing differences in novice and expert responses to CS-specific tasks (Lister et al., 2006). To our knowledge, there is little to no research analyzing state CS standards according to various learning taxonomies.

Methodology

We created a dataset ($n = 9695$) consisting of the state ($n = 42$) K-12 grade CS standards. We assigned each standard to a grade band (i.e., K-2nd, 3rd-5th, 6th-8th, 9th-12th); these grade bands were based on a state's grade level or grade band assignment but do not necessarily match it (for example, some states use 9th-10th and 11th-12th grade bands; we assigned all standards in both bands to the 9th-12th band).

We isolated each standard's (first) verb. Then, we generated a list of the verbs ($n = 51$) that occurred frequently (i.e., at least 30 times) in the dataset. The standards with these verbs ($n = 8622$) were analyzed in this study. We then assigned a Bloom's level and the SOLO level to each standard based on its verb. To assign these levels, we relied on the *Bloom's for Computing: Enhancing Bloom's Revised Taxonomy with Verbs for Computing Disciplines* (ACM Committee for Computing Education in Community Colleges, 2023), which maps verbs to Bloom's levels. For the SOLO levels, we used similar verb lists (Biggs & Tang, 2011; Brabrand & Dahl, 2009). For any verbs not mapped by these sources, we assigned levels based on the categorization of similar verbs.

We calculated the average Bloom's level and average SOLO level for each state. We did this by assigning numerical values to the Bloom's levels and the SOLO levels and then finding the average (mean) of each state's standards. (Note that several states have standards that are identical or nearly identical to the Computer Science Teachers Association (CSTA) standards, so their results below will be virtually identical; these states are Connecticut, Washington, Iowa, Hawaii, Michigan, New Hampshire, and New Mexico.)

Results

Bloom's Taxonomy

As Figure 1 shows, the fewest standards are at the *evaluate* level ($n = 807$), which is the second highest level of Bloom's Taxonomy. The second lowest level, *understand*, has the most standards ($n = 1982$).

SOLO Taxonomy

As shown in Figure 2, the most common SOLO level is *relational*, with about 36% of the standards ($n = 3080$). The least common level is *abstract*, with 7.4% of the standards ($n = 642$).

Higher-Order Thinking Skills

We also analyzed whether each standard represented a higher-order thinking skill (HOTS), defined as belonging to the top three Bloom's levels or the top two SOLO levels (Irvine, 2021). For Bloom's, just over one-third (36.9%) of the standards ($n = 3574$) are classified as HOTS. With SOLO, the percent of HOTS was similar to Bloom's: 38.4% ($n = 3722$). Using Cramer's v, we found a strong correlation, 0.66, between whether a standard was considered a HOTS according each taxonomy.

Comparing Bloom's and SOLO Taxonomies

To determine how much each state's average Bloom's level and SOLO level diverged from the averages for all states, we calculated z-scores. The results for Bloom's are shown in Figure 3. The state with the largest positive divergence is New Jersey, with a z-score of 1.3. The state with the largest negative divergence, Massachusetts, has a z-score of -2.2.

Each state's divergence from the SOLO average is shown in Figure 4. The largest z-score is again New Jersey, this time with score of 2.4. The largest negative divergence is South Carolina, with a z-score of -1.82.

We next calculated the difference between each state's z-scores for Bloom's and for SOLO. Results are shown in Figure 5. On average, states' z-scores for the two taxonomies differed by +/-0.39. The greatest difference was for Florida's z-scores, which differed by -1.3, meaning that its SOLO z-score was larger than its Bloom's z-score. (For states where the Bloom's z-score was larger than the SOLO z-score, the largest difference was Georgia's, which differed by 0.86.) The smallest difference was Wisconsin, with a difference of 0.01.

We also examined how a state's Bloom's and SOLO averages varied across the grade bands. First, we determined whether the average Bloom's level and/or the SOLO level increased at each pair of grade bands. Usually, if the Bloom's average increased, then the SOLO average did as well. However, there are some exceptions. When transitioning from K-2nd to the 3rd-5th grade bands, there is a mismatch (e.g., the Bloom's average increased but the SOLO level did not) for 7% of the states ($n = 3$). For the transition from 3rd-5th to 6th-8th, there is a mismatch for 17% of states, and for the 6th-8th to 9th-12th transition, 12% of states have a mismatch.

Discussion and Conclusion

Bloom's and SOLO can answer similar questions about state CS standards, such as, *What percent of standards cover higher-order thinking skills?* and *How do our state standards' cognitive complexity compare to other states?* However, this study shows that the choice of taxonomy to answer the questions will partially determine the answers. For example, when determining how much each state diverges from the state average in cognitive complexity, New Jersey had the highest positive divergence using both Bloom's and SOLO. However, for Bloom's, 10 other states had z-scores above 1.00, including the group of states that directly adopted the CSTA standards. In contrast, for the SOLO analysis, only three other states had z-scores above 1.00, with the states that directly adopted the CSTA standards falling just below (0.99) that score. Thus, the conclusions reached about how much a state's standards differ in cognitive complexity from the average of all states would likely be somewhat different (with an average absolute z-score difference of 0.39) when measuring cognitive complexity using Bloom's versus using SOLO.

Another way in which the taxonomies differ is in which standards they deem to represent HOTS. While the overall proportion was roughly the same for both taxonomies, the correlation was not quite as strong. Thus, the results of analyzing standards to determine whether they meet goals for higher-order thinking skills will depend to an extent on which taxonomy is chosen for the analysis.

A common concern for writers of state standards is whether the standards show a progression in cognitive complexity as students age. For example, there is often a goal to have high school standards feature greater complexity than middle school standards. Using a learning taxonomy to quantitatively measure progression in cognitive complexity could potentially be a useful tool. However, this study shows that the choice of taxonomy will influence the results, with almost one in five (17%) states differing as to whether the cognitive complexity increased or decreased when comparing the 3rd-5th to the 6th-8th grade bands, depending on which taxonomy was used.

These differences stem from the different levels assigned to verbs by the two taxonomies. As Table 1 shows, verbs at the same level of Bloom's taxonomy are assigned to multiple levels of the SOLO taxonomy and vice versa. For example, there were 10 verbs assigned to the *understand* level of Bloom's taxonomy; of those verbs, two were at SOLO's uni-structural level (*demonstrate* and *observe*), six were at the multistructural level (*describe*, *discuss*, *represent*, *understand*, *classify* and *interpret*), and two were relational (*explain* and *differentiate*).

While these results are an important initial step toward better understanding how Bloom's and SOLO differ, there are some limitations to this work. First, we only analyzed a standard if its (first) verb occurred more than 29 times in the dataset. The decision to omit rare verbs may have influenced our results. Further, there is not always consensus regarding to what level a verb should be assigned according to a learning taxonomy (Newton et al., 2020) – so using different mappings of verbs to levels may have yielded different results. Future work might therefore include more standards, different mapping protocols, and different taxonomies as well.

In a time of rapid scaling of CS education, it is important to design learning standards that show appropriate cognitive complexity. Mapping standards to taxonomies is one way to do that; this work shows how the choice of taxonomy may influence the results of such an analysis.

Acknowledgment

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	Uni-structural	**Multistructural**	**Relational**	**Extended Abstract**
Remember	3	1		
Understand	2	6	2	
Apply	5	5	5	
Analyze		1	7	
Evaluate		3	5	
Create		2	3	1

Table 1

Count of verbs at each SOLO level and Bloom's level

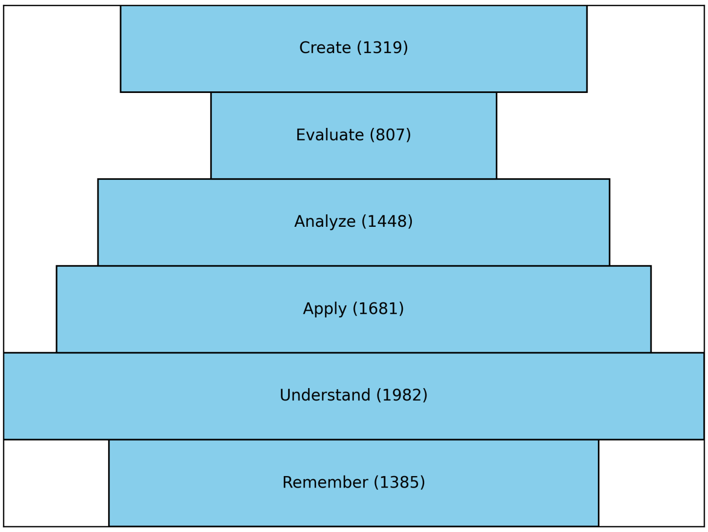

Figure 1. Count of standards by Bloom's Level

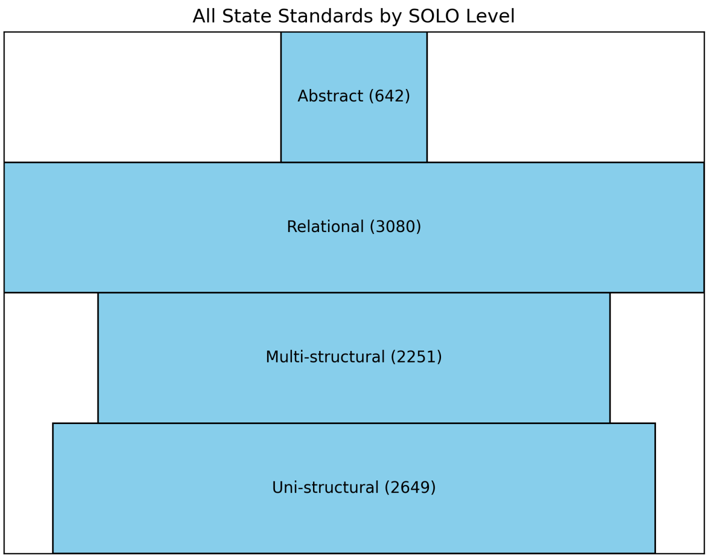

Figure 2. Count of standards by SOLO Level

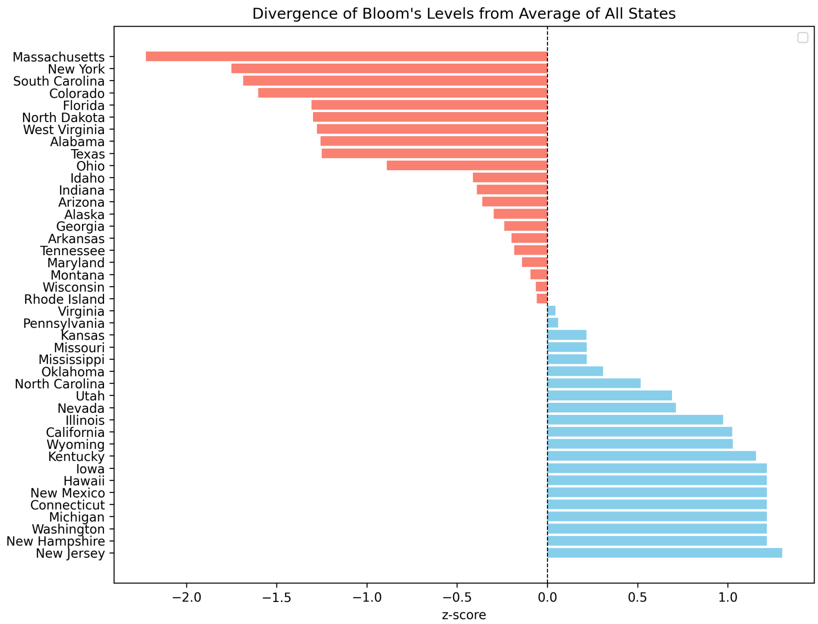

Figure 3. Divergence from the average Bloom's level for all states

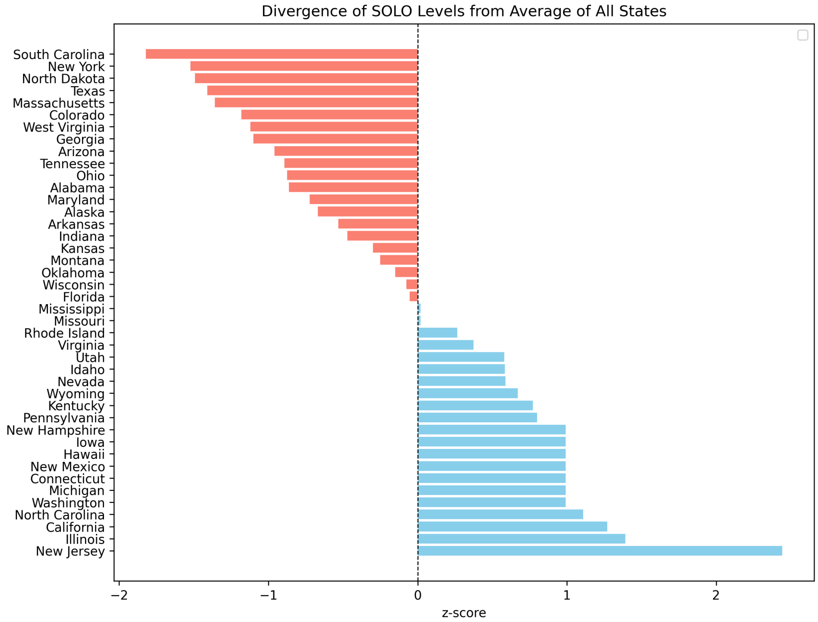

Figure 4. Divergence from the average SOLO level for all states

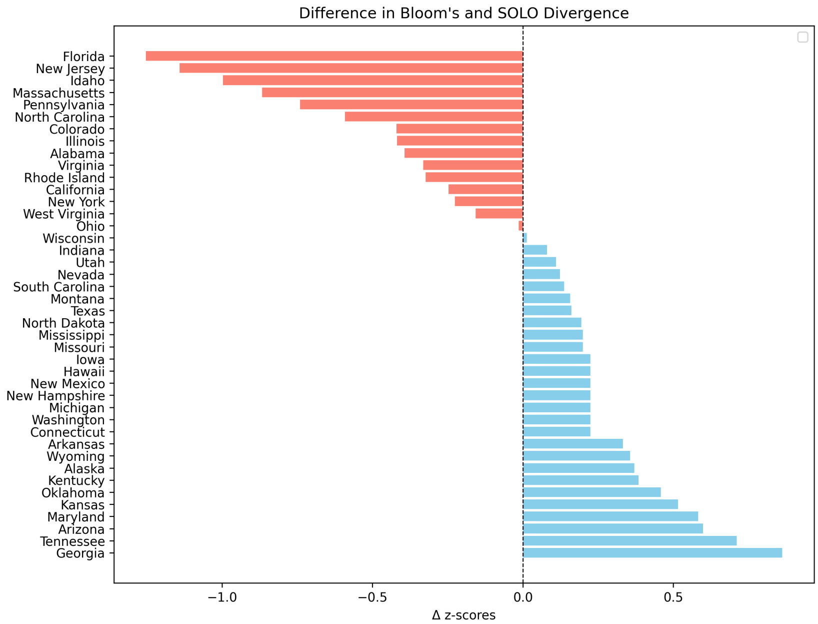

Figure 5. Difference in z-scores for Bloom's and for SOLO by state