Comparison of CSTA Standards to Other Standards and Frameworks

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Introduction

In this document, we present comparisons between the existing Computer Science Teachers Association (CSTA) K–12 Computer Science Standards, the *Reimagining CS Pathways* report, and other sets of standards, frameworks, and instructional guidelines. Table 1 below lists the standards and frameworks we discuss.

Table 1. *Standards and Frameworks in This Report*

CS-Specific Content	Non-CS Content
• Current CSTA K–12 CS Standards • *Reimagining CS Pathways* report • EU *Informatics Reference Framework for School* • Draft AI4K12 Guidelines • K–12 Cybersecurity Learning Standards	*Other STEM Subjects* • Common Core State Standards for Mathematics (CCSSM) • Pre-K–12 Guidelines for Assessment and Instruction in Statistics Education II (GAISE II) • Next Generation Science Standards (NGSS) • Standards for Technological and Engineering Literacy (STEL) *Arts and Humanities* • Common Core State Standards for English Language Arts (CCSSELA) • National Curriculum Standards for Social Studies • National Core Arts Standards • Common Career Technical Core • Social Justice Standards

The goals of these comparisons are to:

- Use the structure of other standards and frameworks to inform the structure of the revised CS standards.
- Identify content from the current CSTA standards that has stood the test of time as well as areas where the field has evolved, and the standards should be updated accordingly.
- Make recommendations for standards writers about the structure and content of the revised CS standards.

Terminology

We review a large number of documents, so we begin by providing brief definitions of the different document types.

- **Standards** are documents that describe what all students should know and be able to do at defined points, generally at the end of each grade level or a grade band. Standards are adopted by individual states and help ensure that all students in that state graduate

from high school with a core set of knowledge and skills for a given discipline. Standards also inform the design of standards-based assessments.

- **Frameworks** provide guidance for developing standards, instruction, curriculum, and course pathways. Frameworks are often written before their corresponding standards, such as the *K–12 Computer Science Framework* (K–12 Computer Science Framework Steering Committee, 2016) guiding the development of the 2017 CSTA K–12 CS Standards and the *Framework for K–12 Science Education* (NRC, 2012) guiding the development of the Next Generation Science Standards (NGSS). Frameworks can also be written after standards adoption to provide updated guidance on how to implement the standards (e.g., the 2023 *California Mathematics Framework* provides new guidance for implementing the 2013 California Common Core State Standards for Mathematics).

Overview of the 2017 CSTA K–12 CS Standards and *Reimagining CS Pathways* Report

Much of this report compares and contrasts the structure and content of the 2017 CSTA K–12 CS Standards, the framework suggested by the *Reimagining CS Pathways* report, with the structure and content of other standards and frameworks. In this section, we provide an orientation to these documents to facilitate such comparisons later in this report.

2016 *K–12 Computer Science Framework* and 2017 CSTA K–12 CS Standards

Content and Organization of the 2016 *K–12 Computer Science Framework*

The *K–12 Computer Science Framework* laid out a vision for K–12 computer science that encompassed seven practices, five core concepts and 17 subconcepts, and five crosscutting concepts. The seven practices are (K–12 CS Framework Steering Committee, 2016, p. 74–82):

1. **Fostering an inclusive computing culture.** Building an inclusive and diverse computing culture requires strategies for incorporating perspectives from people of different genders, ethnicities, and abilities. Incorporating these perspectives involves understanding the personal, ethical, social, economic, and cultural contexts in which people operate. Considering the needs of diverse users during the design process is essential to producing inclusive computational products.

2. **Collaborating around computing.** Collaborative computing is the process of performing a computational task by working in pairs and on teams. Because it involves asking for the contributions and feedback of others, effective collaboration can lead to better outcomes than working independently. Collaboration requires individuals to navigate and incorporate diverse perspectives, conflicting ideas, disparate skills, and distinct personalities. Students should use collaborative tools to effectively work together and to create complex artifacts.

3. **Recognizing and defining computational problems.** The ability to recognize appropriate and worthwhile opportunities to apply computation is a skill that develops over time and is central to computing. Solving a problem with a computational approach

requires defining the problem, breaking it down into parts, and evaluating each part to determine whether a computational solution is appropriate.

4. **Developing and using abstractions.** Abstractions are formed by identifying patterns and extracting common features from specific examples to create generalizations. Using generalized solutions and parts of solutions designed for broad reuse simplifies the development process by managing complexity.

5. **Creating computational artifacts.** The process of developing computational artifacts embraces both creative expression and the exploration of ideas to create prototypes and solve computational problems. Students create artifacts that are personally relevant or beneficial to their community and beyond. Computational artifacts can be created by combining and modifying existing artifacts or by developing new artifacts. Examples of computational artifacts include programs, simulations, visualizations, digital animations, robotic systems, and apps.

6. **Testing and refining computational artifacts.** Testing and refinement is the deliberate and iterative process of improving a computational artifact. This process includes debugging (identifying and fixing errors) and comparing actual outcomes to intended outcomes. Students also respond to the changing needs and expectations of end users and improve the performance, reliability, usability, and accessibility of artifacts.

7. **Communicating about computing.** Communication involves personal expression and exchanging ideas with others. In computer science, students communicate with diverse audiences about the use and effects of computation and the appropriateness of computational choices. Students write clear comments, document their work, and communicate their ideas through multiple forms of media. Clear communication includes using precise language and carefully considering possible audiences.

CS Practices 3–6 are designated as computational thinking practices. In the *K–12 Computer Science Framework*, the practices are written as end points for grade 12, with no further breakdown by individual grade or grade band.

The five core concepts and 17 subconcepts are (K–12 CS Framework Steering Committee, 2016, p. 89–92):

1. **Computing Systems.** People interact with a wide variety of computing devices that collect, store, analyze, and act upon information in ways that can affect human capabilities both positively and negatively. The physical components (hardware) and instructions (software) that make up a computing system communicate and process information in digital form. An understanding of hardware and software is useful when troubleshooting a computing system that does not work as intended.

   Subconcepts:

   a. Devices
   b. Hardware and Software
   c. Troubleshooting

2. **Networks and the Internet.** Computing devices typically do not operate in isolation. Networks connect computing devices to share information and resources and are an increasingly integral part of computing. Networks and communication systems provide

greater connectivity in the computing world by providing fast, secure communication and facilitating innovation.

Subconcepts:

a. Network Communication and Organization
b. Cybersecurity

3. **Data and Analysis.** Computing systems exist to process data. The amount of digital data generated in the world is rapidly expanding, so the need to process data effectively is increasingly important. Data is collected and stored so that it can be analyzed to better understand the world and make more accurate predictions.

   Subconcepts:

   a. Collection
   b. Storage
   c. Visualization and Transformation
   d. Inference and Models

4. **Algorithms and Programming.** An algorithm is a sequence of steps designed to accomplish a specific task. Algorithms are translated into programs, or code, to provide instructions for computing devices. Algorithms and programming control all computing systems, empowering people to communicate with the world in new ways and solve compelling problems. The development process to create meaningful and efficient programs involves choosing which information to use and how to process and store it, breaking apart large problems into smaller ones, recombining existing solutions, and analyzing different solutions.

   Subconcepts:

   a. Algorithms
   b. Variables
   c. Control
   d. Modularity
   e. Program Development

5. **Impacts of Computing.** Computing affects many aspects of the world in both positive and negative ways at local, national, and global levels. Individuals and communities influence computing through their behaviors and cultural and social interactions, and in turn, computing influences new cultural practices. An informed and responsible person should understand the social implications of the digital world, including equity and access to computing.

   Subconcepts:

   a. Culture
   b. Social Interactions
   c. Safety, Law, and Ethics

For each subconcept, the *K–12 Computer Science Framework* describes the key understandings that students should have by the end of grades 2, 5, 8, and 12.

The five crosscutting concepts are "themes that illustrate connections among different concept statements" (K–12 CS Framework Steering Committee, 2016, p. 87):

1. **Abstraction.** An abstraction is the result of reducing a process or set of information to a set of important characteristics for computational use. Abstractions establish interactions at a level of reduced complexity by managing the more complex details below the level of interaction. An abstraction can be created to generalize a range of situations by picking out common properties minus specific implementation details.

2. **System Relationships.** The parts of a system are interdependent and organized for a common purpose. A systems perspective provides the opportunity to decompose complex problems into parts that are easier to understand, develop, fix, and maintain. General systems principles include feedback, control, efficiency, modularity, synthesis, emergence, and hierarchy.

3. **Human-Computer Interaction.** Humans interact directly with computers such as laptops and smartphones but also other devices, such as cars and home appliances, which have embedded computers. Developing effective and accessible user interfaces involves the integration of technical knowledge and social science and encompasses both designer and user perspectives.

4. **Privacy and Security.** Privacy is the ability to seclude information and express it selectively. It includes controls for the collection, access, use, storage, sharing, and alteration of information. Security refers to the safeguards surrounding information systems and includes protection from theft or damage to hardware, software, and the information in the systems. Security supports privacy.

5. **Communication and Coordination.** Processes in computing are characterized by the reliable exchange of information between autonomous agents (communication) that cooperate toward common outcomes that no agent could produce alone (coordination). Communication and coordination are distinct but not independent processes. What is special about computing is the scale at which communication and coordination work.

Content and Organization of the 2017 CSTA K–12 CS Standards

The 2017 CSTA K–12 CS Standards largely adopt the practices and concept structure of the *K–12 Computer Science Framework*, but there are a few minor changes. The 2017 CSTA K–12 CS Standards do not explicitly include the crosscutting concepts, though the themes themselves still appear in the standards. The 2017 CSTA K–12 CS Standards use five grade bands instead of four, dividing high school into two separate sets of standards: K–2, 3–5, 6–8, 9–10 (high school core), and 11–12 (high school specialty). The 2017 CSTA K–12 CS Standards also combine the Collection and Visualization and Transformation subconcepts for Data and Analysis into a single subconcept. Table 2 shows the number of standards for each concept, subconcept, and grade band.

The CSTA K–12 CS Standards explicitly link one or more practices to each standard. There is variation in how frequently each practice appears in each grade band (see Table 2), but in a full implementation of the standards, students will have the opportunity to engage with each practice in each grade band (see Table 3).

Table 2. *Number of 2017 CSTA K–12 CS Standards by Concept, Subconcept, and Grade Band*

Concept	Subconcept	K–2	3–5	6–8	9–10	11–12	Total
Computing Systems *- 14 standards*	Devices	1	1	1	1	--	4
	Hardware and Software	1	1	1	1	1	5
	Troubleshooting	1	1	1	1	1	5
Networks and the Internet *- 13 standards*	Network Communication and Organization	--	1	1	3	1	6
	Cybersecurity	1	1	2	2	1	7
Data and Analysis *- 15 standards*	Collection, Visualization, and Transformation	1	1	1	1	2	6
	Storage	1	--	1	2	--	4
	Inference and Models	1	1	1	1	1	5
Algorithms and Programming *- 56 standards*	Algorithms	1	1	1	1	4	8
	Variables	1	1	1	1	1	5
	Control	1	1	1	2	1	6
	Modularity	1	2	2	3	3	11
	Program Development	4	5	5	4	8	26
Impacts of Computing *- 22 standards*	Culture	1	2	2	3	3	11
	Social Interactions	1	1	1	1	--	4
	Safety, Law, and Ethics	1	1	1	3	1	7
Total		18	21	23	30	28	120

Table 3. *Frequency of CSTA K–12 CS Practices Across Grade Bands*

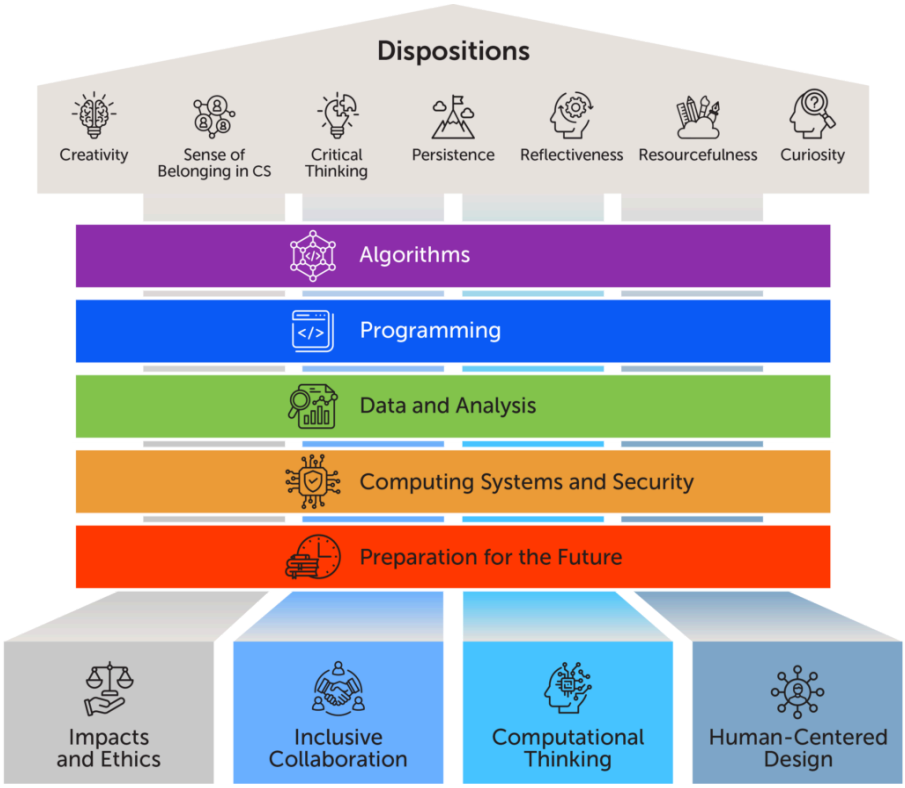
CS Practice	K–2	3–5	6–8	9–10	11–12	Total
1	1	3	2	2	2	**10**
2	1	1	3	2	1	**8**
3	1	4	2	5	2	**14**
4	5	2	7	7	6	**27**
5	2	5	6	4	6	**23**
6	2	3	3	3	3	**14**
7	9	6	5	7	10	**37**

Reimagining CS Pathways Report

The *Reimagining CS Pathways* report is an updated framework intended to inform the revision of the 2017 CSTA K–12 CS Standards.

The *Reimagining CS Pathways* report reorganizes the concepts and practices from the *K–12 Computer Science Framework* into five Topic Areas and four Pillars.

The Topic Areas "reflect the content that is essential for all high school graduates" (CSTA et al., 2024, p. 4), and the Pillars represent "essential ideas and practices that cut across all of the Topic Areas" (CSTA et al., 2024, p. 4).



The *Reimagining CS Pathways* structure combines the Computing Systems and the Networks and the Internet core concepts from the *K–12 Computer Science Framework* into one Topic Area and divides the Algorithms and Programming core concept into two distinct Topic Areas in order to better balance the content. The Data and Analysis core concept is maintained as a single Topic Area.

The *Reimagining CS Pathways* report also creates a new Topic Area: Preparation for the Future. Preparation for the Future contains "two threads: 1) the student's own future, specifically pathways and careers that involve computing in some respect and 2) emerging technologies, including their societal implications and ethical issues" (CSTA et al., 2024, p. 23).

For each of the five Topic Areas, the *Reimagining CS Pathways* report describes a set of learning outcomes for high school graduates. The learning outcomes are organized using six levels based on Bloom's Revised Taxonomy (ACM Committee for Computing Education in Community Colleges, 2023; Geissler et al., 2023):

1. Remember
2. Understand
3. Apply
4. Analyze
5. Evaluate
6. Create

The *Reimagining CS Pathways* report converted Impacts of Computing from a core concept to a Pillar. Similarly, computational thinking and collaboration are represented as Pillars instead of as a series of practices. A new Pillar, Human-Centered Design, "encompasses aspects of planning that are user-focused" (CSTA et al., 2024, p. 18). This Pillar elevates and expands on some skills and processes that were previously part of the Program Development subconcept of Algorithms and Programming.

The *Reimagining CS Pathways* report also introduces seven Dispositions:

- Creativity
- Sense of Belonging in CS
- Critical Thinking
- Persistence
- Reflectiveness
- Resourcefulness
- Curiosity

The Dispositions are "broad-based habits of mind that are not discipline-specific" (Claxton, 2009, as cited in CSTA et al., 2024, p. 14). The goal is to develop these dispositions in students, but they do not have to be explicitly taught.

CS-Specific Standards and Frameworks

EU *Informatics Reference Framework for School*

The EU *Informatics*[1] *Reference Framework for School* was published in 2022, and it is unclear if it has been used. The framework contains a minimum set of high-level requirements for informatics curricula. The following is an explanation of the framework from the website:

> The report outlines an informatics reference framework for education in school which is intended to offer high-level guidance that may be used by, and indeed stimulate, curriculum designers to review their focus and approach to the subject of informatics…
>
> The document is deliberately synthetic and short, to provide a minimum set of high-level common requirements, leaving space for the national communities of colleagues in various countries to derive fully-fledged curricula both attuned to their culture and needs, and coherent with a common European vision of informatics. (Caspersen et al., 2022)

The framework describes five overall aims and objectives for the end of upper secondary informatics education in the EU (Caspersen et al., 2022, p. 5):

1. Use digital tools in a conscious, responsible, confident, competent, and creative way.
2. Understand the phenomena, concepts, principles, and practices of informatics and the multifaceted ways of applying them to model, interpret, and operate on reality.

[1] "Informatics," as used in this framework, is synonymous with computing, computing science, and computer science (Caspersen et al., 2022).

3. Analyze, design, frame, and solve problems by devising representations, designing algorithmic solutions, and implementing these in a programming language.

4. Develop computational models to creatively investigate, understand, and communicate about natural and artificial phenomena and systems.

5. Identify, analyze, and discuss ethical and social issues associated with computational systems and their use as well as their potential benefits and risks.

The framework covers eleven core topic areas (Caspersen et al., 2022, p. 5):

- Data and information
- Algorithms
- Programming
- Computing systems
- Networks and communication
- Human–computer interaction
- Design and development
- Digital creativity
- Modelling and simulation
- Privacy, safety, and security
- Responsibility and empowerment

We will summarize the commonalities and differences between the CSTA K–12 CS Standards and EU Informatics Reference Framework below.

Content and Organization of the Framework

The CSTA K–12 CS Standards are two-dimensional, and the EU Informatics Reference Framework is one-dimensional. Both have a dimension around concepts; however, the CSTA K–12 CS Standards include practices as a separate dimension while the EU Informatics Reference Framework does not. The CSTA K–12 CS Standards have five grade bands.

The EU Informatics Reference Framework includes 11 core topic areas without any subtopics (see Table 4). The core topic areas include a brief description as well as more detail into how one might interpret and expand those topics into a contemporary context.

The EU Informatics Reference Framework does not include learning standards or progressions but does include some indicators of outcomes for each topic area broken down into three grade bands: primary, lower secondary, and upper secondary (see Table 5 for examples).

Table 4. *Core Topic Areas of the EU Informatics Reference Framework for School (Caspersen et al., 2022, p. 5)*

Core Topic Area	Description
Data and information	Understand how data are collected, organised, analysed and used to model, represent and visualise information about real-world artefacts and scenarios.
Algorithms	Evaluate, specify, develop, and understand algorithms.
Programming	Use programming languages to express oneself computationally by developing, testing and debugging digital artefacts; and understand what a programming language is.
Computing systems	Understand what a computing system is, how its constituent parts function together as a whole, and its limitations.
Networks and communication	Understand how networks enable computing systems to share information via interfaces and protocols, and how networks may introduce risks.
Human-computer interaction	Evaluate, specify, develop and understand interaction between people and computing artefacts.
Design and development	Plan and create computing artefacts taking into account stakeholders' viewpoints and critically evaluating alternatives and their outcomes.
Digital creativity	Explore and use digital tools to develop and maintain computing artefacts, also using a range of media.
Modelling and simulation	Evaluate, modify, design, develop, and understand models and simulations of natural and artificial phenomena and their evolution.
Privacy, safety and security	Understand risks when using digital technology, and how to protect individuals and systems.
Responsibility and empowerment	Critically and constructively analyse concrete computing artefacts as well as advanced and potentially controversial techniques and applications of informatics, particularly from an ethical and social perspective.

Table 5. *Examples of Indicators of Outcomes for Programming in the EU* Informatics Reference Framework for School *(Caspersen et al., 2022, p. 11)*

Level	Examples of Indicators of Outcomes
P	Design, create, test and evaluate simple programs and determine whether they execute as intended; the programs may involve the use of conditionals and loops. Identify and correct errors in simple programs.
L	Design, create, test and evaluate programs that demonstrate the use of simple algorithms, possibly accessing data from a sensor or reading data from a file. Ensure that both programs and their specifications are simple and easy to understand as well as being mutually consistent; and use one strategy to assist with problem-solving, and demonstrate its application.
U	Write routines to solve specific problems and demonstrate the ability to use routines in programs of their own creation. Use decomposition to structure programs in a modular way.

Comparison to CSTA K–12 CS Standards

The EU Informatics Reference Framework was designed to "offer high-level guidance" for curriculum designers. All of the content in the EU Informatics Reference Framework overlaps with the CSTA K–12 CS Standards, which suggests there is alignment between the two standards/frameworks.

AI4K12 Guidelines

The AI4K12 guidelines are intended to be guidelines for teaching AI at the K–12 level. Development started in 2018. The guidelines have been drafted and are open for feedback. The development of the guidelines was sponsored by the Association for the Advancement of Artificial Intelligence (AAAI) and CSTA. The team on the project included educators from each grade band and professionals from academia and industry. "The guidelines will serve as a framework to assist standards writers and curriculum developers on AI concepts, essential knowledge, and skills by grade band" (AI4K12, 2020).

Content and Organization of the Framework

The guidelines are organized around the 5 Big Ideas in AI: Perception, Representation & Reasoning, Learning, Natural Interaction, and Societal Impact (see Table 6). The guidelines include the knowledge students should learn about AI and how they should use that knowledge and are organized in grade-band progression charts. The AI4K12 guidelines are one-dimensional; they do not have practices.

Table 6. *Big Ideas of the AI4K12 (AI4K12, 2020)*

Core Topic Area	Description
Perception	Computers perceive the world using sensors. Perception is the process of extracting meaning from sensory signals. Making computers "see" and "hear" well enough for practical use is one of the most significant achievements of AI to date.
Representation & Reasoning	Agents maintain representations of the world and use them for reasoning. Representation is one of the fundamental problems of intelligence, both natural and artificial. Computers construct representations using data structures, and these representations support reasoning algorithms that derive new information from what is already known. While AI agents can reason about very complex problems, they do not think the way a human does.
Learning	Computers can learn from data. Machine learning is a kind of statistical inference that finds patterns in data. Many areas of AI have progressed significantly in recent years thanks to learning algorithms that create new representations. For the approach to succeed, tremendous amounts of data are required. This "training data" must usually be supplied by people, but is sometimes acquired by the machine itself.
Natural Interaction	Intelligent agents require many kinds of knowledge to collaborate and interact naturally with humans. Ideally, agents will converse with us using natural language, draw upon cultural knowledge to infer intentions from observed behavior, and respond appropriately to body language, facial expressions, and emotions. Advances in deep neural networks such as large language models and convolutional neural networks are making this possible.
Societal Impact	AI can impact society in both positive and negative ways. AI technologies are changing the ways we work, travel, communicate, and care for each other. But we must be mindful of the harms that can potentially occur. For example, biases in the data used to train an AI system could lead to some people being less well served than others. Thus, it is important to discuss the impacts that AI is having on our society and develop criteria for the ethical design and deployment of AI-based systems.

In the AI4K12 guidelines, each Big Idea is divided into 3–4 concepts (specific topics within the Big Ideas), which are often divided into smaller subconcepts. Each subconcept includes a *Learning Objective* that defines what students should be able to do and an *Enduring Understanding* that defines what students should know (AI4K12, 2020). Some subconcepts also include an *Unpacked* (further explanation to help illustrate concepts), examples, activities, and/or other resources. Most subconcepts are included in each grade band. The grade band that included the fewest subconcepts was K–2. Big Idea 3: Learning included the fewest subconcepts for K–2, with only five out of 11 concepts being included in that grade band. Tables 7–11 show the subconcepts that are included in each grade band.

Table 7. *Number of Standards for Each Concept in Big Idea 1: Perception*

Concept	K–2	3–5	6–8	9–12
Sensing	2	3	3	2
Processing	4	4	4	4
Domain Knowledge	2	2	2	2

Table 8. *Number of Standards for Each Concept in Big Idea 2: Representation and Reasoning*

Concept	K–2	3–5	6–8	9–12
Representation	4	4	4	4
Search	2	2	2	2
Reasoning	2	2	2	2

Table 9. *Number of Standards for Each Concept in Big Idea 3: Learning*

Concept	K–2	3–5	6–8	9–12
Nature of Learning	3	6	5	5
Neural Networks	0	2	2	2
Datasets	2	3	3	3

Table 10. *Number of Standards for Each Concept in Big Idea 4: Natural Interaction*

Concept	K–2	3–5	6–8	9–12
Natural Language	4	4	4	4
Commonsense Reasoning	1	1	1	1
Understanding Emotion	1	1	1	1
Philosophy of Mind	1	1	1	1

Table 11. *Number of Standards for Each Concept in Big Idea 5: Societal Impact*

Concept	K–2	3–5	6–8	9–12
Ethical AI	2	3	3	3
AI & Culture	1	2	2	2
AI & the Economy	2	2	2	2
AI for Social Good	1	2	2	2

The AI4K12 guidelines have a total of 165 standards. Although the AI4K12 guidelines are intended to “define what every student should know about AI and what they should be able to do with it,” there are enough learning objectives that incorporating them all into the revised CS standards seems implausible.

The AI4K12 guidelines have one fewer grade band compared to the 2017 CSTA K–12 CS Standards: K–2, 3–5, 6–8, 9–12, banding all of high school together instead of having separate bands for 9–10 and 11–12. Table 12 shows an example of a progression of standards for the concept Sensing, which is under Big Idea 1: Perception. AI4K12 defines perception as “the extraction of meaning from sensory information using knowledge” (AI4K12, 2020).

Table 12. *Example of AI4K12 Guidelines for Big Idea 1: Perception – Sensing*

Concept	K–2	3–5	6–8	9–12
Sensing (Living Things) **1-A-i**	**LO:** Identify human senses and sensory organs. **EU:** People experience the world through sight, hearing, touch, taste, and smell.	**LO:** Compare human and animal perception. **EU:** Some animals experience the world differently than people do. **Unpacked:** Bats and dolphins use sonar. Bees can see ultraviolet. Rats have no color vision; dogs are red-green colorblind. Dogs and rats can hear higher frequencies than humans.	**LO:** Give examples of how humans combine information from multiple modalities. **EU:** People can exploit correlations between senses, such as sight and sound, to make sense of ambiguous signals. **Unpacked:** In a noisy environment, speech is more understandable when the speaker's mouth is visible. People learn the sounds associated with various actions (such as dropping an object) and can recognize when the sound doesn't match their expectation.	N/A—For AI purposes, this topic has already been adequately addressed in the lower grade bands. *Other courses, such as biology or an elective on sensory psychology, could go into more detail about topics such as taste, smell, proprioception, and vestibular organs.* *Possible enrichment material: look at optical illusions (Muller-Lyer illusion, Kanizsa triangle) and ask which ones are computer vision systems also subject to.*

LO = Learning Objective; **EU** = Enduring Understanding

Comparison to CSTA K–12 CS Standards

There is a significant amount of content in the AI4K12 guidelines that has no obvious analogue in the 2017 CSTA K–12 CS Standards. The CS Standards only explicitly mention artificial intelligence in the Algorithms & Programming concept area in the 11–12 grade band, though foundational AI concepts around data, data representations, and algorithms appear elsewhere (see Table 13).

The strongest connections between the concept areas in the CSTA K–12 CS Standards and the Big Ideas in the AI4K12 guidelines are between Impacts of Computing and Societal Impact. Other connections between the CSTA K–12 CS Standards and the AI4K12 include: 1) Data and Analysis and Perception and Representation & Reasoning; 2) Algorithms and Programming and Representation & Reasoning, Learning, and Societal Impact; and 3) Impacts of Computing and Societal Impact. The *Reimagining CS Pathways* report lists Artificial Intelligence as a priority area for foundational content, but purposely does not treat it as a discrete topic. Instead, foundational AI understanding is woven throughout the topic areas and can be specially addressed as part of the Preparation for the Future topic.

Table 13. *Intersection of AI4K12 Guidelines to* Reimagining CS Pathways *and CSTA K–12 CS Standards*

Reimagining CS Pathways	**CSTA K–12 CS Standards and *K–12 CS Framework***	**AI4K12**				
		Perception	**Representation & Reasoning**	**Learning**	**Natural Interaction**	**Societal Impact**
Computing Systems and Security	Computing Systems					
	Networks and the Internet					
Data and Analysis	Data and Analysis	■	■			
Algorithms	Algorithms and Programming		■	■		■
Programming						
Impacts and Ethics	Impacts of Computing					■
N/A	N/A	■	■	■	■	■

K–12 Cybersecurity Learning Standards

The K-12 Cybersecurity Learning Standards were developed by CYBER.ORG in partnership with K–12 educators, university faculty, and industry and government cybersecurity professionals. They were published in 2021 and are available "for districts and educators to incorporate into existing curricula opportunities or course standards" (K–12 Cybersecurity Learning Standards, 2021). We are not aware of any curricula outside of CYBER.ORG's that have incorporated these standards.

Content and Organization of the Standards

The K–12 Cybersecurity Learning Standards are one-dimensional and do not include practices. The K–12 Cybersecurity Learning Standards have four grade bands (K–2, 3–5, 6–8, 9–12), combining all high school standards into one band.

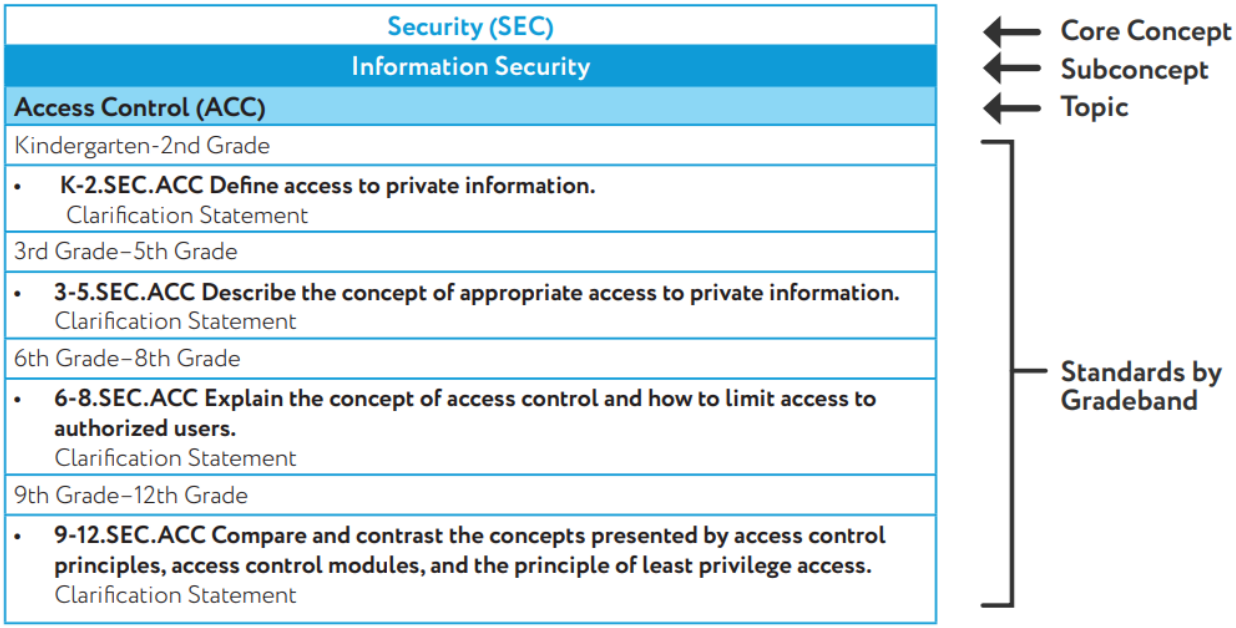


Figure 1. *Sample Standard From the K–12 Cybersecurity Learning Standards (K–12 Cybersecurity Learning Standards, 2021, p. 6)*

There are four aspects to each standard, as shown in Figure 1:

Core concepts are the major ideas that are fundamental in cybersecurity education (K–12 Cybersecurity Learning Standards, 2021, p. 6).

Subconcepts represent specific ideas within the core concepts (K–12 Cybersecurity Learning Standards, 2021, p. 6).

Topics represent specific content areas within the subconcept and core concept (K–12 Cybersecurity Learning Standards, 2021, p. 6).

Standards by grade band define what students should understand and be able to do in each grade band (K–12 Cybersecurity Learning Standards, 2021, p. 6).

The K–12 Cybersecurity Learning Standards are arranged into core concepts: computing systems; digital citizenship; and security (Caspersen et al., 2022, p. 36).

- **Computing Systems** include hardware and software that work together to achieve objectives. Cybersecurity professionals work to prevent adversaries from exploiting weaknesses in computing systems to disrupt confidentiality, integrity, or availability.
- **Digital citizenship** encompasses the responsible and appropriate use of technology within society, including the norms, expectations, laws, and policies that affect organizations and individuals.
- **Security** is characterized by the user's responsibility for protection of access to computer networks, secure entry to all physical devices, and inherent accountability to protect personal identification information and organizational data.

The core concepts each contain three subconcepts, and the subconcepts are further broken down into 2–5 topics (see Table 14). There are standards for each topic in each grade band. All topics have at least one standard for each grade band. The Cybersecurity Learning Standards has a total of 123 standards.

Table 14. *The Core Concepts, Subconcepts, and Topics in the K–12 Cybersecurity Standards (Caspersen et al., 2022, p. 5)*

Core Concept	Subconcept	Topics
Computing Systems	Communication and Networking	Network Communication, Network Components, Cloud Computing, Protocols, Data Loss
	Hardware	Network Hardware Components, Internet of Things, Operating Systems
	Software	Software Updates, Programming and Scripting, Applications
Digital Citizenship	Online Safety	Cyberbullying, Digital Footprint, Personally Identifiable Information
	Ethics	Threat Actors, Ethical Integrity
	Policy and Legal Issues	Rules, Laws, and Regulations; Intellectual Property; Usage and User Agreements
Security	Information Security	CIA Triad, Access Control, Data Security, Threats and Vulnerabilities, Cryptography
	Network Security	Authentication, Securing Network Components, Threats and Vulnerabilities
	Physical Security	Threats and Vulnerabilities, Security Controls

Comparison to CSTA K–12 CS Standards

Similar to the AI4K12 guidelines, the K–12 Cybersecurity Learning Standards contain a large number of standards, and it seems unlikely for all standards to be integrated into the revised CS standards.

The subconcepts of the Cybersecurity Learning Standards overlap with three of the CS standards concepts. From the Cybersecurity Learning Standards, the digital citizenship concept only overlaps with Impacts of Computing. Similarly, the Security concept only overlaps with Networks and the Internet. The Computing Systems concept from the Cybersecurity Learning Standards overlaps with two CS standards concepts: Computing Systems and Networks and the Internet. Not all standards from each set of standards had a match. Tables 15–17 summarize the topics that do and do not overlap between the two sets of standards.

Oftentimes, when there was a match, the CS standards were more generalized and encompassed multiple Cybersecurity standards (illustrated in Table 18). The Cybersecurity Learning Standards also included very specific security topics, such as Defense in Depth and Confidentiality, Integrity, and Availability (CIA) Triad.

We also observed differences in the verbs used in the standards. The Cybersecurity Learning Standards often used verbs such as describe, recognize, examine, and compare and contrast. The CS standards included verbs similar to those listed above but also used ones such as model, develop, decompose, and create. This indicates that the Cybersecurity Learning Standards largely focus on understanding and verbalizing knowledge while the CS standards also include the implementation of the knowledge students learn.

Table 15. *Topics Covered by Both the Cybersecurity Learning Standards and the 2017 CSTA K–12 CS Standards*

Topic	Description
Authentication	Authentication provides a method for identifying users. The authentication process typically requires valid user credentials, confirmed by something you know, something you have, something you are, somewhere you are, or something you do (Caspersen et al., 2022, p. 37).
Network Hardware Components	Devices (hardware) that are connected to or comprise a network (Caspersen et al., 2022, p. 39).
Personally Identifiable Information	Data which can be used to identify a specific individual (Caspersen et al., 2022, p. 39).
Encryption	The conversion of electronic data into another form, called ciphertext, which cannot be easily understood by anyone except authorized parties (K–12 CS Framework Steering Committee, 2016).
Protocol	A communications standard often consisting of the structure and formatting used in the exchange of information (Caspersen et al., 2022, p. 39).
Securing Network Components	Ensuring that devices that are connected to a network are secure.
Threats and Vulnerabilities	Potential attacks to computing systems and any weaknesses in the systems.
Applications	The role that software and software developers play in protecting devices and information.
Ethics	The practice of recognizing and applying responsible decision-making to understand the impacts, rights, responsibilities, and consequences of computing technologies and behaviors

Table 16. *Topics Only Covered by 2017 CSTA K–12 CS Standards*

Topic	Description
Scalability and Reliability	Understand factors that affect the scalability and reliability of networks.
Troubleshooting	A systematic approach to problem-solving that is often used to find and resolve a problem, error, or fault within software or a computing system (K–12 CS Framework Steering Committee, 2016).
Selecting and Operating Software	Selecting and using software to complete tasks.
Design of Computing Devices	Designing computing devices to address users' needs.
Software and Hardware	How software and hardware work together and function as a system.

Table 17. *Topics Only Covered by K–12 Cybersecurity Learning Standards*

Topic	Description
Cyberbullying	The use of electronic communication to bully a person typically by sending messages of an intimidating or threatening nature (Massachusetts Department of Elementary and Secondary Education, 2019).
Digital Footprint	Public and private information available on the internet which comprise an identity, both real and virtual (Caspersen et al., 2022, p. 38).
Internet of Things	Internet-connected devices that automatically carry out some function in daily life (e.g., thermostat, doorbell) (Caspersen et al., 2022, p. 38).
Cloud Computing	Computing resources shared over a network where the internal structure is abstracted from the end user (Caspersen et al., 2022, p. 36).
Data Loss	Actions that can be taken to prevent the loss of data.

Table 18. *Example of a Generalized CSTA CS Standard That Encompasses Multiple K–12 Cybersecurity Learning Standards*

CSTA K–12 CS Standards and *K–12 CS Framework*	K–12 Cybersecurity Learning Standards
2-NI-05 [6–8] - Explain how physical and digital security measures protect electronic information.	K–2.SEC.NET Identify methods for exchanging information and why they need to be protected. 3–5.SEC.NET Discuss vulnerabilities of open methods for exchanging information. K–2.SEC.PHYS Define physical security as it relates to cybersecurity. 3–5.SEC.PHYS Explain the need to protect people and places from malicious intent. 6–8.SEC.PHYS Explain how malicious actions threaten physical security. 9–12.SEC.PHYS Analyze the different types of attacks that affect physical security. K–2.SEC.CTRL Define the policy of “trust but verify” for identity assurance. 3–5.SEC.CTRL Identify physical access controls found in everyday life. 6–8.SEC.CTRL Describe Defense in Depth and how physical access controls work together. 9–12.SEC.CTRL Justify the use of Defense in Depth and the need for physical access controls.

Other STEM Standards and Frameworks

Common Core State Standards for Mathematics

The Common Core State Standards for Mathematics (CCSSM) were published in 2010 and initially adopted by 41 states. The CCSSM are currently adopted in nine states with many more states adopting CCSSM-like standards. The following explanation of the standards is summarized from the introduction to the CCSSM.

> These Standards define what students should understand and be able to do in their study of mathematics. Asking a student to understand something means asking a teacher to assess whether the student has understood it….
>
> The Standards set grade-specific standards but do not define the intervention methods….[they] provide clear signposts along the way to the goal of college and career readiness for all students. (CCSSO, 2010b, p. 4)

The authors of the CCSSM also developed *Progressions for the Common Core State Standards for Mathematics* (Common Core Standards Writing Team, 2023), which is a companion document that more deeply describes how mathematics topics develop and connect across grade levels. The *Progressions* are intended to inform the development of curriculum and teacher preparation.

Standards for Mathematical Practice and Comparisons to CS Practices

The CCSSM includes grade-specific content standards as well as eight mathematical practice standards. The practice standards describe habits of mind and connect to mathematical content across all grade levels and domains. The Standards for Mathematical Practice (SMPs) are (CCSSO, 2010b, p. 6):

1. **Make sense of problems and persevere in solving them.**
   Mathematically proficient students start by explaining to themselves the meaning of a problem and looking for entry points to its solution. They analyze givens, constraints, relationships, and goals. They make conjectures about the form and meaning of the solution and plan a solution pathway rather than simply jumping into a solution attempt. They consider analogous problems, and try special cases and simpler forms of the original problem in order to gain insight into its solution. They monitor and evaluate their progress and change course if necessary…. Mathematically proficient students can explain correspondences between equations, verbal descriptions, tables, and graphs or draw diagrams of important features and relationships, graph data, and search for regularity or trends…. Mathematically proficient students check their answers to problems using a different method, and they continually ask themselves, “Does this make sense?” They can understand the approaches of others to solving complex problems and identify correspondences between different approaches.

2. **Reason abstractly and quantitatively.**
   Mathematically proficient students make sense of quantities and their relationships in problem situations. They bring two complementary abilities to bear on problems involving quantitative relationships: the ability to decontextualize—to abstract a given

situation and represent it symbolically and manipulate the representing symbols as if they have a life of their own, without necessarily attending to their referents—and the ability to contextualize, to pause as needed during the manipulation process in order to probe into the referents for the symbols involved. Quantitative reasoning entails habits of creating a coherent representation of the problem at hand; considering the units involved; attending to the meaning of quantities, not just how to compute them; and knowing and flexibly using different properties of operations and objects.

3. **Construct viable arguments and critique the reasoning of others.**
Mathematically proficient students understand and use stated assumptions, definitions, and previously established results in constructing arguments. They make conjectures and build a logical progression of statements to explore the truth of their conjectures. They are able to analyze situations by breaking them into cases, and can recognize and use counterexamples. They justify their conclusions, communicate them to others, and respond to the arguments of others. They reason inductively about data, making plausible arguments that take into account the context from which the data arose. Mathematically proficient students are also able to compare the effectiveness of two plausible arguments, distinguish correct logic or reasoning from that which is flawed, and—if there is a flaw in an argument—explain what it is….

4. **Model with mathematics.**
Mathematically proficient students can apply the mathematics they know to solve problems arising in everyday life, society, and the workplace. In early grades, this might be as simple as writing an addition equation to describe a situation…. Mathematically proficient students who can apply what they know are comfortable making assumptions and approximations to simplify a complicated situation, realizing that these may need revision later. They are able to identify important quantities in a practical situation and map their relationships using such tools as diagrams, two-way tables, graphs, flowcharts and formulas. They can analyze those relationships mathematically to draw conclusions. They routinely interpret their mathematical results in the context of the situation and reflect on whether the results make sense, possibly improving the model if it has not served its purpose.

5. **Use appropriate tools strategically.**
Mathematically proficient students consider the available tools when solving a mathematical problem. These tools might include pencil and paper, concrete models, a ruler, a protractor, a calculator, a spreadsheet, a computer algebra system, a statistical package, or dynamic geometry software. Proficient students are sufficiently familiar with tools appropriate for their grade or course to make sound decisions about when each of these tools might be helpful, recognizing both the insight to be gained and their limitations…. Mathematically proficient students at various grade levels are able to identify relevant external mathematical resources, such as digital content located on a website, and use them to pose or solve problems. They are able to use technological tools to explore and deepen their understanding of concepts.

6. **Attend to precision.**
Mathematically proficient students try to communicate precisely to others. They try to use clear definitions in discussion with others and in their own reasoning. They state the meaning of the symbols they choose, including using the equal sign consistently and appropriately. They are careful about specifying units of measure, and labeling axes to

> clarify the correspondence with quantities in a problem. They calculate accurately and efficiently, express numerical answers with a degree of precision appropriate for the problem context…
>
> 7. **Look for and make use of structure.**
> Mathematically proficient students look closely to discern a pattern or structure…. They also can step back for an overview and shift perspective. They can see complicated things, such as some algebraic expressions, as single objects or as being composed of several objects…..
>
> 8. **Look for and express regularity in repeated reasoning.**
> Mathematically proficient students notice if calculations are repeated, and look both for general methods and for shortcuts…. As they work to solve a problem, mathematically proficient students maintain oversight of the process, while attending to the details. They continually evaluate the reasonableness of their intermediate results.

Both the CSTA K–12 CS Standards and the CCSSM are two-dimensional, with standards and practices. In the CCSSM, there is one set of practices to be applied to all grade levels. The full descriptions of the practices refer to the ways that "younger students" and "older students" should engage with mathematics as they develop understanding, but like the CS practices, there is no breakdown by individual grade or grade band.

The CSTA K–12 CS Standards and the CCSSM are different in the way the practices are integrated into the standards. Where the CSTA K–12 CS Standards explicitly incorporate one or more practices into each content standard, the CCSSM only provides general guidance on integrating the content standards and the practices.

> Designers of curricula, assessments, and professional development should all attend to the need to connect the mathematical practices to mathematical content in mathematics instruction.
>
> The Standards for Mathematical Content are a balanced combination of procedure and understanding. Expectations that begin with the word "understand" are often especially good opportunities to connect the practices to the content. Students who lack understanding of a topic may rely on procedures too heavily…. In short, a lack of understanding effectively prevents a student from engaging in the mathematical practices (CCSSO, 2010b, p. 8).

This lack of explicit integration between the content and the practices can make it challenging to effectively implement the practices. Bill McCallum, one of the lead writers of the CCSSM, wrote on his blog: "If you think about it long enough you can associate just about any practice standard with any content standard, but this sort of matrix thinking can lead to a dilution of the force of the practice standards—if you try to do everything all the time, you end up doing nothing" (McCallum, 2011).

The nature of the practices also differs between the CSTA K–12 CS Standards and the CCSSM (see Appendix A for a table that compares practices side-by-side). CS Practices 3–6 are considered the computational thinking practices "at the heart of computer science" (K–12 CS Framework Steering Committee, 2016, p. 67) and are similar to the engineering design cycle used in the Next Generation Science Standards. CS Practices 1, 2, and 7 are described in the

K–12 Computer Science Framework as "general practices in computer science that complement computational thinking" (K–12 CS Framework Steering Committee, 2016, p. 67), but could also be thought of as practices that address the human and social aspects of computing.

In contrast, the SMPs reflected "'processes and proficiencies' with longstanding importance in mathematics education," such as problem-solving and problem-solving strategy, reasoning and proof, communication, conceptual understanding, procedural fluency, and productive dispositions (CCSSO, 2010b, p. 9). Although this is not made explicit in the standards themselves, the CCSSM authors grouped the practices into four categories (McCallum, 2011):

1. Overarching habits of mind of a productive mathematical thinker (SMP1 and SMP6)
2. Reasoning and explaining (SMP2 and SMP3)
3. Modeling and using tools (SMP4 and SMP5)
4. Seeing structure and generalizing (SMP7 and SMP8)

The developers of Bootstrap, a curriculum that integrates CS and math, have noted the usefulness of the practices around problem-solving and productive dispositions for CS, but they are relatively absent in the CS practices (Fisler et al., 2021). These practices appear in the *Reimagining CS Pathways* report as *dispositions*, particularly critical thinking and persistence (CSTA et al., 2024).

Nonetheless, there are commonalities between the CS practices and the SMPs, as identified in the *K–12 Computer Science Framework* (K–12 CS Framework Steering Committee, 2016):

- Define problems (SMP1, CS3)
- Develop and use abstractions (SMP2, SMP7, SMP8, CS4)
- Communicate rationale (SMP3, CS7)
- Model (SMP4, CS4, CS6)
- Use tools when collaborating (SMP5, CS2)
- Communicate precisely (SMP6, CS7)

Content and Grade-Level Organization of the Standards

There are three aspects to each standard, as shown in Figure 2:

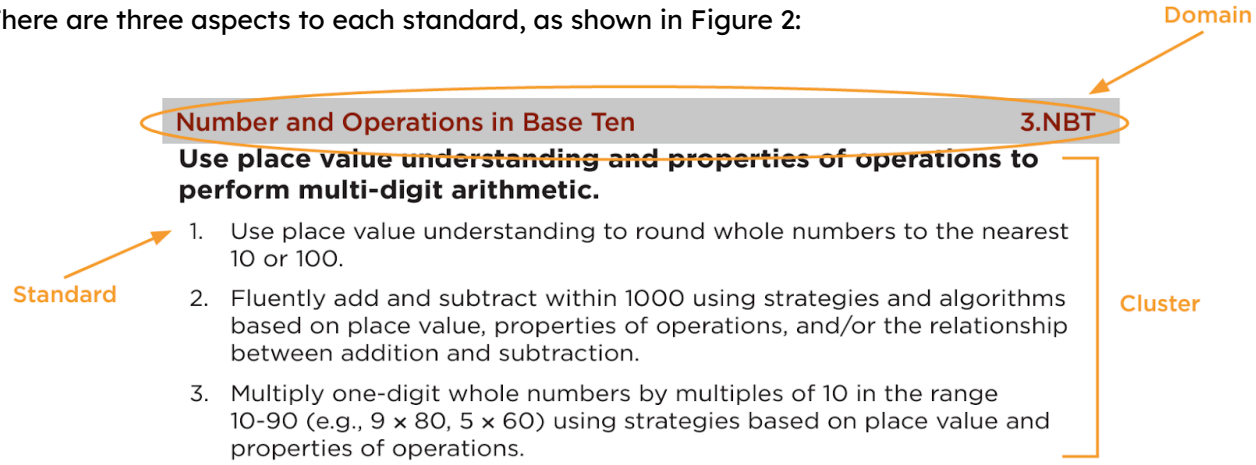


Figure 2. *Example CCSSM Cluster With Multiple Standards*

Standards define what students should understand and be able to do. In some cases, standards will have substandards.

Clusters are groups of related standards. Note that standards from different clusters may sometimes be closely related, because mathematics is a connected subject.

Domains are larger groups of related standards. Standards from different domains may sometimes be closely related (CCSSO, 2010b, p. 5).

The K–12 CS content standards are structured differently than the CCSSM. The CCSSM contains content standards for individual grade levels from K–8 and then standards for the high school grade band. In the CS standards, each concept area is divided into 2–5 subconcept areas. There are standards for each concept area and subconcept area in each grade band. In the CCSSM, the related groups of standards in each grade level are organized into clusters (see Figure 2), and there are multiple clusters for each domain. There are 11 total domains across K–8. In high school, there are six conceptual categories instead of standards for individual grades. The conceptual categories each contain their own domains. The shift from individual grade-level standards in K–8 to conceptual categories in high school allows for a variety of course progressions through high school. The goal is for any high school math sequence to collectively address all the standards within the high school grade band, with the exception of standards indicated as necessary for students to take advanced courses in high school or beyond.

The domains and conceptual categories are organized to reflect the logical progression of mathematics knowledge, with less complex domains at the lower grades replaced by more advanced content domains at the upper grades. Only the Geometry domain appears in every grade level. Figure 3 shows some examples of how the domains connect across grade bands.

<table>
<tr><th>Grades K–5</th><th></th><th>Grades 6–8</th><th></th><th>High School</th></tr>
<tr><td>Operations and Algebraic Thinking</td><td>➡</td><td>Expressions and Equations</td><td>➡</td><td rowspan="2">Functions, Algebra</td></tr>
<tr><td>Number and Operations — Fractions</td><td>➡</td><td>Ratio and Proportional Relationships</td><td>➡</td></tr>
<tr><td>Measurement and Data</td><td>➡</td><td colspan="3">Statistics and Probability</td></tr>
</table>

Figure 3. *Examples of How Some CCSSM Domains Progress Across Grade Bands*

Table 19 shows the distribution of CCSSM domains and standards/substandards across the grade levels. The Counting and Cardinality domain only appears in kindergarten. Four domains are exclusive to grades K–5, three domains are exclusive to grades 6–8, and three conceptual categories are exclusive to high school.

The standard clusters within each CCSSM domain often do not repeat across grade bands. Even when they do, the content of the cluster evolves to reflect more advanced learning. For example, as shown in Table 20, the Operations & Algebraic Thinking domain contains four clusters in grade 1 but three clusters in grade 2. As further detailed in Table 21, two of the grade 2 clusters also appear in grade 1, but the standards within each cluster represent more advanced learning in grade 2.

Table 19. *Distribution of CCSSM Domains and Standards Across Grade Levels*

Domain	K	1	2	3	4	5	6	7	8	HS
Counting and Cardinality	10	-	-	-	-	-	-	-	-	-
Operations and Algebraic Thinking	5	8	4	9	5	3	-	-	-	-
Number and Operations in Base Ten	1	9	11	3	6	9	-	-	-	-
Number and Operations—Fractions	-	-	-	9	14	14	-	-	-	-
Ratio and Proportional Relationships	-	-	-	-	-	-	8	7	-	-
The Number System	-	-	-	-	-	-	15	11	2	-
Expressions and Equations	-	-	-	-	-	-	12	6	13	-
Functions	-	-	-	-	-	-	-	-	5	45
Number and Quantity	-	-	-	-	-	-	-	-	-	32
Algebra	-	-	-	-	-	-	-	-	-	34
Measurement and Data	3	4	10	14	9	10	-	-	-	-
Statistics and Probability	-	-	-	-	-	-	9	13	4	36
Modeling[2]										
Geometry	6	3	3	2	3	4	4	6	12	45
Total # Standards/Substandards	25	24	28	37	37	40	48	43	36	192

Table 20. *Clusters in the Operations & Algebraic Thinking Domain for Grade 1 and Grade 2*

Grade 1	Grade 2
1. Represent and solve problems involving addition and subtraction	1. Represent and solve problems involving addition and subtraction
2. Understand and apply properties of operations and the relationship between addition and subtraction	2. Add and subtract within 20
3. Add and subtract within 20	3. Work with equal groups of objects to gain foundations for multiplication
4. Work with addition and subtraction equations	

[2] Modeling is addressed in SMP4 and thus should appear in all grade levels. In high school, modeling is not a standalone conceptual category. Instead, specific standards throughout the high school standards are designated as modeling standards.

Table 21. *Progression of Two Clusters From Grade 1 to Grade 2*

Grade 1	Grade 2
Represent and solve problems involving addition and subtraction	
1. Use addition and subtraction within 20 to solve word problems involving situations of adding to, taking from, putting together, taking apart, and comparing, with unknowns in all positions (e.g., by using objects, drawings, and equations with a symbol for the unknown number to represent the problem). 2. Solve word problems that call for addition of three whole numbers whose sum is less than or equal to 20 (e.g., by using objects, drawings, and equations with a symbol for the unknown number to represent the problem).	1. Use addition and subtraction within 100 to solve one- and two-step word problems involving situations of adding to, taking from, putting together, taking apart, and comparing, with unknowns in all positions (e.g., by using drawings and equations with a symbol for the unknown number to represent the problem).
Add and subtract within 20	
1. Relate counting to addition and subtraction (e.g., by counting on 2 to add 2). 2. Add and subtract within 20, demonstrating fluency for addition and subtraction within 10. Use strategies such as counting on; making ten (e.g., 8 + 6 = 8 + 2 + 4 = 10 + 4 = 14); decomposing a number leading to a ten (e.g., 13 – 4 = 13 – 3 – 1 = 10 – 1 = 9); using the relationship between addition and subtraction (e.g., knowing that 8 + 4 = 12, one knows 12 – 8 = 4); and creating equivalent but easier or known sums (e.g., adding 6 + 7 by creating the known equivalent 6 + 6 + 1 = 12 + 1 = 13).	1. Fluently add and subtract within 20 using mental strategies. By the end of Grade 2, know from memory all sums of two one-digit numbers.

Connections to Computer Science

There are two CCSSM domains that are strongly connected to the Data and Analysis content described in the 2017 CSTA K–12 CS Standards and the *Reimagining CS Pathways* report: 1) Measurement and Data and 2) Statistics and Probability. As described earlier, these two domains form a progression from foundational measurement concepts to statistical modeling. There are also some connections to Geometry, Expressions and Equations, Functions, and Modeling standards. We will address these connections in more detail in the Recommendations for Standards Writers: Data and Analysis section.

Guidelines for Assessment and Instruction in Statistics Education II

The Guidelines for Assessment and Instruction in Statistics Education II (GAISE II), published in 2020, is a curriculum framework for Pre-K–12 education to help all students "achieve data literacy and become statistically literate" (Bargagliotti et al., 2020, p. 5). It was created through a joint effort of the American Statistical Association and the National Council of Teachers of Mathematics. It is not officially adopted as a framework for any U.S. states, but it influenced the 2023 California Math Framework and is a foundational document for national efforts to create learning progressions and assessments for K–12 data science.

Content and Level Organization of the GAISE II

Because it is a framework and not a set of standards, the structure of the GAISE II is very different from that of the existing CSTA K–12 CS Standards. The GAISE II is organized around a statistical problem-solving process with four components (see Figure 4):

1. Formulate statistical investigative questions
2. Collect/consider the data
3. Analyze the data
4. Interpret the results

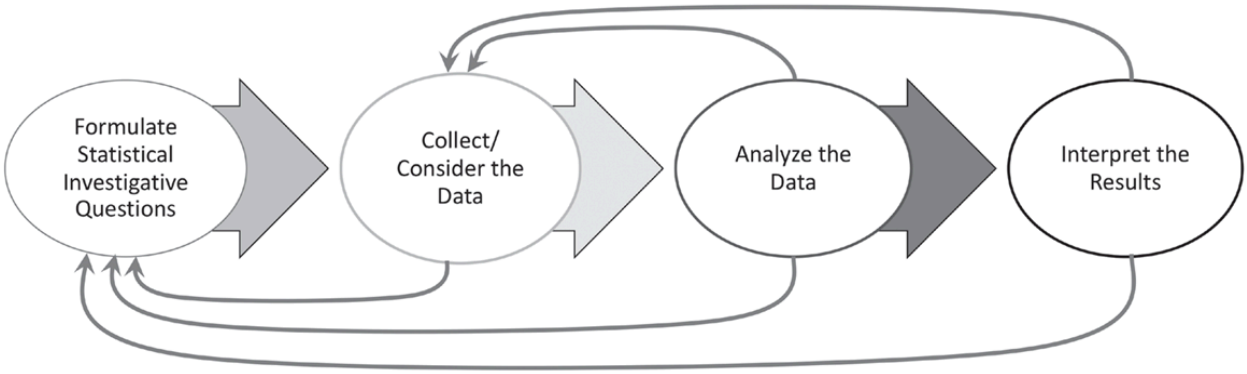


Figure 4. *Statistical Problem-Solving Process From GAISE II (Bargagliotti et al., 2020, p. 13)*

The content for each process component is then divided into three levels: A, B, and C. The authors of the GAISE II are very explicit that these levels are not intended to map onto specific grade levels.

> …a middle school student who has had no prior experience with statistics will need to begin with Level A concepts and activities before moving to Level B. This prerequisite holds for a secondary student as well. If a student has not had Level A and B experiences prior to high school, then it is not appropriate for that student to begin with Level C expectations (Bargagliotti et al., 2020, p. 15).

The GAISE II does not have practices as a distinct dimension—the entire framework is devoted to supporting the practice of statistical problem-solving.

The GAISE II does not divide the four process components into subcomponents. Instead, there are instructional recommendations, not standards, for each level. When the instructional recommendations are combined across process components within a level, students will engage in a complete statistical investigation. As an example, Table 22 shows all the recommendations for Level A (Bargagliotti et al., 2020, pp. 22–23).

Table 22. *GAISE II Level A Instructional Recommendations*

Process Component	Level A Recommendations
I. Formulate statistical investigative questions	Understand when a statistical investigation is appropriate Pose statistical investigative questions of interest to students where the context is such that students can collect or have access to all required data Pose summary (or descriptive) statistical investigative questions about one variable regarding small, well-defined groups (e.g., subset of a classroom, classroom, school, town) and extend these to include comparison and association statistical investigative questions between variables Experience different types of questions in statistics: those used to frame an investigation, those used to collect data, and those used to guide analysis and interpretation
II. Collect/consider data	Understand that data are information; recognize that to answer a statistical investigative question, a person may collect data themselves specifically for that purpose, or a person may use data that have been collected by other people for another purpose Understand how to collect and record information from the group of interest using surveys, and measurements collected from observations and simple experiments Understand that a variable measures the same characteristic on several individuals or objects and results in data values that may fluctuate Understand that within a dataset, there can be different types of variables (e.g., categorical or quantitative) Interrogate the dataset to understand the context of the variables and how they may relate to statistical investigative questions Understand that data are not always pristine but may contain errors, have missing values, etc., and that decisions have to be made about how to account for these issues

Process Component	Level A Recommendations
III. Analyze the data	Understand that the distribution of a categorical variable or a discrete quantitative variable describes the number of times a particular outcome occurs Represent the variability of categorical variables or quantitative variables using appropriate displays (e.g., tables, picture graphs, dotplots, bar graphs) Describe key features of distributions for quantitative variables such as: • Center: mean as the equal share, and median as the middle-ordered value of the data • Variability: range as the difference between the greatest and least value, and dispersion as how many units from the equal share value • Shape: number of clusters, symmetric or not, and gaps Recognize that distributions can be used to compare two groups Observe whether there appears to be an association between two variables
IV. Interpret the results	Use statistical evidence from analyses to answer the statistical investigative questions and communicate results through structured answers with teacher guidance Make statements about the group or population from which the data were collected, recognizing that these conclusions are limited to these groups and cannot be generalized to other groups Describe the difference between two groups with different conditions

Table 23. *Summary of Transitions in GAISE II Levels*

Step	Level A	Level B	Level C
I	Understand and experience different types of statistical investigative questions. Pose statistical investigative questions involving familiar contexts and small datasets.	Understand that there are different types of statistical investigative questions and that they can be used to articulate research topics. Pose statistical investigative questions about a broader population or changes over time that involve bigger datasets collected from devices.	Pose more complex statistical investigative questions, such as those involving multiple variables or requiring causal inference. Determine how data can be collected and analyzed to answer the questions.

Step	Level A	Level B	Level C
II	Understand the basic properties of datasets and the variables within them and how data can be collected. Interrogate datasets to understand the variables and how they relate to statistical investigative questions.	Understand that data are collected with a purpose and can be organized and stored in a variety of structures (e.g., spreadsheets). Recognize the limitations of datasets and data collection methods. Interrogate datasets to determine how the data were collected and understand the variables in the data. Understand how sampling and random assignment are used to answer statistical investigative questions	Distinguish between different types of statistical investigations, such as surveys, observational studies, and experiments. Understand good practices for sampling, data collection, and data handling. Apply practices when collecting primary data or selecting data for secondary analysis. Understand more complex considerations around research design, such as the role of random sampling in surveys, random assignment in experiments, issues around bias and confounding variables, and the generality of findings.
III	Understand and represent data distributions for categorical and quantitative variables. Describe data distributions for quantitative variables using their measures of center, variability, and shape. Compare distributions and identify associations between variables.	Visualize data distributions for quantitative variables. Use measures of center, variability, and shape to reason about two distributions and compare them. Explore patterns of association between two variables.	Use technology to subset, filter, and transform data. Summarize and describe relationships among multiple variables by visualizing the data and calculating summary statistics and confidence intervals. Use simulations to understand and approximate sampling distributions and to investigate associations between categorical variables.
IV	Use evidence to answer statistical investigative questions and communicate results with teacher guidance.	Use statistical evidence to answer statistical investigative questions and communicate results comprehensively, with some teacher guidance. State the limitations of the sample and recognize the uncertainty in generalizing beyond the sample. Compare results for different conditions in an experiment.	Use statistical evidence to answer statistical investigative questions and communicate results through formal reports and presentations. Understand how missing data and outliers may influence an analysis. Understand how to interpret margins of error and p-values.

The nature of the statistical problem-solving process stays consistent as students progress from Level A to Level C—students pose statistical investigative questions, examine and analyze data, and use statistical evidence at every level. As students progress through the levels, their understanding of the statistical problem-solving process becomes more advanced. Table 23 summarizes the major transitions from Level A to C in each step of the problem-solving process. The majority of the GAISE II document is devoted to examples of statistical investigations appropriate for each level.

Connections to Computer Science

As with the CCSSM, the CS standards' main connection to the GAISE II will be through the Data and Analysis topic area, particularly learning outcomes DA.13–16 described in the *Reimagining CS Pathways* report. We will address these connections in more detail in the Recommendations for Standards Writers: Data and Analysis section.

Next Generation Science Standards

The Next Generation Science Standards (NGSS Lead States, 2013) were developed based on the National Research Council's (NRC) *K–12 Framework for Science Education* (NRC, 2012) through a collaborative, state-led process. The NGSS were released in 2013 and are currently adopted in 20 states. The NGSS are accompanied by a large number of appendices and other supporting documents to explain the standards, connect the NGSS to other disciplines, describe some implementation models, and document the standards development process (NGSS, n.d.).

Science and Engineering Practices and Comparisons to CS Practices

The NGSS contains three dimensions, which were defined in the *K–12 Framework for Science Education* (NRC, 2012). Like in the 2017 CSTA K–12 CS Standards and the CCSSM, one of the dimensions is composed of practices. There are eight science and engineering practices (SEPs). These eight practices were derived from an analysis of what professional scientists and engineers do (NGSS Lead States, 2013, Appendix F). NGSS defines what elements of each practice students should master at the end of each grade band (K–2, 3–5, 6–8, 9–12), but the intent is for all students to engage in all eight practices in all grade bands, with students' use of the practices growing in complexity and sophistication over time. The eight SEPs are:

1. **Asking Questions and Defining Problems**
   Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations. For engineering, they should ask questions to define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution. (NRC, 2012, p. 56)

2. **Developing and Using Models**
   Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures" and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system. (NRC, 2012, p. 58)

3. **Planning and Carrying Out Investigations**
   Students should have opportunities to plan and carry out several different kinds of investigations during their K–12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g., measuring specific properties of materials)—to those that emerge from students' own questions. (NRC, 2012, p. 61)

4. **Analyzing and Interpreting Data**
   Once collected, data must be presented in a form that can reveal any patterns and relationships and that allows results to be communicated to others. Because raw data as such have little meaning, a major practice of scientists is to organize and interpret data through tabulating, graphing, or statistical analysis. Such analysis can bring out the meaning of data—and their relevance—so that they may be used as evidence.

   Engineers, too, make decisions based on evidence that a given design will work; they rarely rely on trial and error. Engineers often analyze a design by creating a model or prototype and collecting extensive data on how it performs, including under extreme conditions. Analysis of this kind of data not only informs design decisions and enables the prediction or assessment of performance but also helps define or clarify problems, determine economic feasibility, evaluate alternatives, and investigate failures. (NRC, 2012, pp. 61–62)

5. **Using Mathematics and Computational Thinking**
   Although there are differences in how mathematics and computational thinking are applied in science and in engineering, mathematics often brings these two fields together by enabling engineers to apply the mathematical form of scientific theories and by enabling scientists to use powerful information technologies designed by engineers. Both kinds of professionals can thereby accomplish investigations and analyses and build complex models, which might otherwise be out of the question. (NRC, 2012, p. 65)

6. **Constructing Explanations and Designing Solutions**
   Asking students to demonstrate their own understanding of the implications of a scientific idea by developing their own explanations of phenomena, whether based on observations they have made or models they have developed, engages them in an essential part of the process by which conceptual change can occur.

   In engineering, the goal is a design rather than an explanation. The process of developing a design is iterative and systematic, as is the process of developing an explanation or a theory in science. Engineers' activities, however, have elements that are distinct from those of scientists. These elements include specifying constraints and criteria for desired qualities of the solution, developing a design plan, producing and testing models or prototypes, selecting among alternative design features to optimize the achievement of design criteria, and refining design ideas based on the performance of a prototype or simulation. (NRC, 2012, pp. 68–69)

7. **Engaging in Argument from Evidence**
   The study of science and engineering should produce a sense of the process of argument necessary for advancing and defending a new idea or an explanation of a phenomenon and the norms for conducting such arguments. In that spirit, students should argue for the explanations they construct, defend their interpretations of the associated data, and advocate for the designs they propose. (NRC, 2012, p. 73)

8. **Obtaining, Evaluating, and Communicating Information**
   Any education in science and engineering needs to develop students' ability to read and produce domain-specific text. As such, every science or engineering lesson is in part a language lesson, particularly reading and producing the genres of texts that are intrinsic to science and engineering. (NRC, 2012, p. 76)

The *K–12 Computer Science Framework* (K–12 CS Framework Steering Committee, 2016) identified areas of overlap between the CS practices and the SEPs, some of which also overlap with the SMPs (see Appendix A):

- Define problems (SEP1, CS3)
- Model (SEP2, CS4, CS6)
- Create artifacts (SEP3, SEP6, CS4, CS5, CS6)
- Communicate with data (SEP4, CS7)
- Use computational thinking (SEP5, CS3, CS4, CS5)
- Communicate rationale (SEP7, SEP8, CS7)

Disciplinary Core Ideas and Crosscutting Concepts

The *K–12 Framework for Science Education* (NRC, 2012) described two additional dimensions of science knowledge and skills. The Disciplinary Core Ideas (DCIs) are the key ideas in science and are grouped into four science domains: 1) Physical Science, 2) Life Science, 3) Earth and Space Science, and 4) Engineering, Technology, and the Applications of Science. The science domains and DCIs are somewhat analogous to the concept and subconcept areas of the 2017 CSTA K–12 CS Standards, though there are significantly more DCIs in the NGSS than there are subconcepts in CS. Table 24 shows the number of DCIs for each science domain.

Table 24. *Number of DCIs in NGSS Science Domains*

Science Domain	# of DCIs
Physical Science	12
Life Science	14
Earth and Space Science	12
Engineering, Technology, and the Applications of Science	3

Crosscutting concepts (CCCs), which are the third dimension, connect the four domains. There are seven CCCs: 1) Patterns, 2) Cause and Effect, 3) Scale, Proportion, and Quantity, 4) Systems and System Models, 5) Energy and Matter, 6) Structure and Function, and 7) Stability and Change.

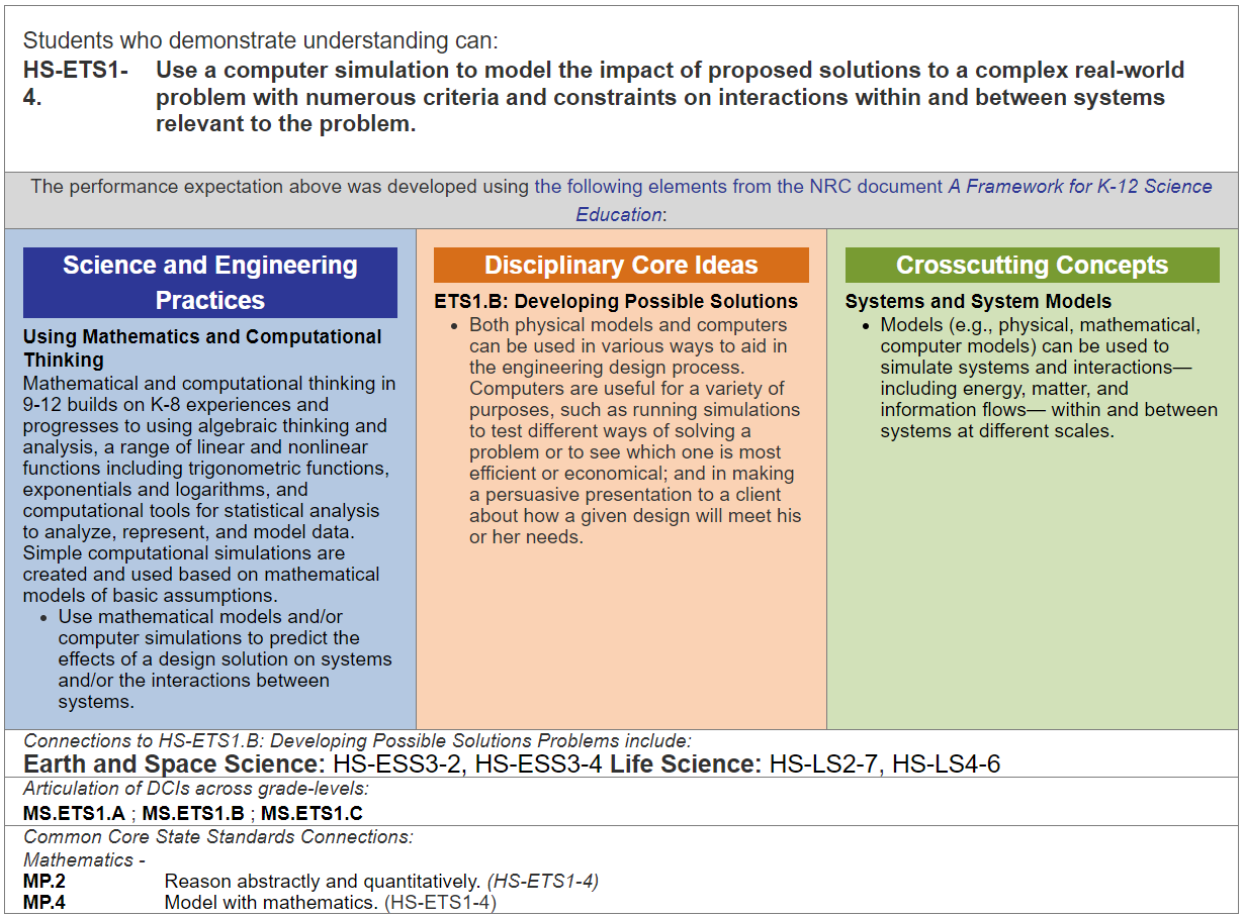
Content and Grade Level Organization of the NGSS

NGSS standards are organized in a table with three sections, as shown in Figure 5:

1. **Performance expectations.** These "state what students should be able to do in order to demonstrate that they have met the standard" (NGSS, 2013, p. 1) after instruction. The performance expectations can include additional statements to clarify the expectation and establish assessment boundaries. The performance expectations are written to allow for multiple means of assessment. All students should be held accountable for demonstrating achievement of all performance expectations.

2. **Foundations**. Each set of performance expectations is constructed from a subset of the practices, DCIs, and CCCs, which are listed in the colored boxes in the middle of the table.

3. **Connections.** The NGSS describes three types of connections for each set of performance expectations: a) connections to other DCIs in the same grade level, b) articulation of DCIs across grade levels, and c) connections to the Common Core State Standards.



Students who demonstrate understanding can:

HS-ETS1-4. **Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.**

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking

Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems.

Disciplinary Core Ideas

ETS1.B: Developing Possible Solutions

- Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.

Crosscutting Concepts

Systems and System Models

- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales.

Connections to HS-ETS1.B: Developing Possible Solutions Problems include:

Earth and Space Science: HS-ESS3-2, HS-ESS3-4 **Life Science:** HS-LS2-7, HS-LS4-6

Articulation of DCIs across grade-levels:

MS.ETS1.A ; **MS.ETS1.B** ; **MS.ETS1.C**

Common Core State Standards Connections:

Mathematics -

MP.2 Reason abstractly and quantitatively. *(HS-ETS1-4)*

MP.4 Model with mathematics. (HS-ETS1-4)

Figure 5. *Example NGSS Standard*

For Physical Science, Life Science, and Earth and Space Science, the NGSS defines performance expectations for each grade from K–5 and then the 6–8 and 9–12 grade bands. For Engineering, the NGSS defines performance expectations for grade bands only: K–2, 3–5, 6–8, and 9–12. Table 25 shows the number of performance expectations for each science domain in each grade or grade band.

Table 25. *Number of Performance Expectations for NGSS Science Domains by Grade*

Science Domain	K	1	2	3	4	5	6–8	9–12
Physical Science	4	4	4	4	7	6	21	19
Life Science	1	3	8	8	2	3	21	24
Earth and Space Science	5	2	3	3	5	5	15	19
Engineering, Technology, and the Applications of Science	3			3			4	4
Total # Performance Expectations	10+3	9+3	15+3	15+3	14+3	14+3	61	66

Connections to Computer Science

There are several areas of the NGSS with strong connections to computer science. There are multiple practices that overlap between the NGSS and the 2017 CSTA K–12 CS Standards, as described above. Our recommendations for the Data and Analysis topic area focus on the connections to the NGSS SEP4: Analyzing and interpreting data, and SEP 5: Using mathematics and computational thinking.

In addition, there is a strong connection between the engineering domain and CS. The engineering domain contains three DCIs, which are close analogues to CS practices 3, 5, and 6 in the 2017 CSTA K–12 CS Standards:

ETS1A: Defining and delimiting engineering problems
ETS1B: Designing solutions to engineering problems
ETS1C: Optimizing the design solution

The NGSS approach to engineering design also aligns with the Computational Thinking and Human-Centered Design Pillars from the *Reimagining CS Pathways* report. Students encounter increasingly complex engineering design problems in each grade band, which are summarized in Table 26 (NGSS, 2013, Appendix I).

Table 26. *Summary of NGSS Engineering Design Problems by Grade Band*

Grade Band	ETS1A: Define	ETS1B: Design	ETS1C: Optimize
K–2	Identify situations that people want to change as problems that can be solved through engineering	Convey possible solutions through visual or physical representations	Compare solutions, test them, and evaluate each
3–5	Specify criteria and constraints that a possible solution to a problem must meet	Research and explore multiple possible solutions	Improve a solution based on results of simple tests, including failure points
6–8	Attend to precision of criteria and constraints and considerations likely to limit possible solutions	Combine parts of different solutions to create new solutions	Use systematic processes to iteratively test and refine a solution
9–12	Attend to a broad range of considerations in criteria and constraints for problems of social and global significance	Break a major problem into smaller problems that can be solved separately	Prioritize criteria, consider trade-offs, and assess social and environmental impacts as a complex solution is tested and refined

Standards for Technological and Engineering Literacy

The Standards for Technological and Engineering Literacy (STEL) were developed by the International Technology and Engineering Educators Association (ITEEA) and its Council on Technology and Engineering Teacher Education (CTETE) in 2020. The standards are intended to describe "what students should know and be able to do in order to be technologically and engineering literate" (ITEEA, 2020, p. ix) but does not define a curriculum model. STEL highlights "the interdisciplinary nature of study in technology and engineering, in which social, ethical, economic, environmental, and aesthetic factors must be considered alongside technical factors" (ITEEA, 2020, p. ix).

STEL is organized around three dimensions: core disciplinary standards, technology and engineering practices (TEPs), and technology and engineering contexts, as shown in Figure 6. The authors of STEL imagined this as a set of rotating octagons, allowing the core standards to be taught using a variety of practices and across different contexts (see Figure 6). The STEL authors intended for educators to focus on the core disciplinary standards and the TEPs during implementation.

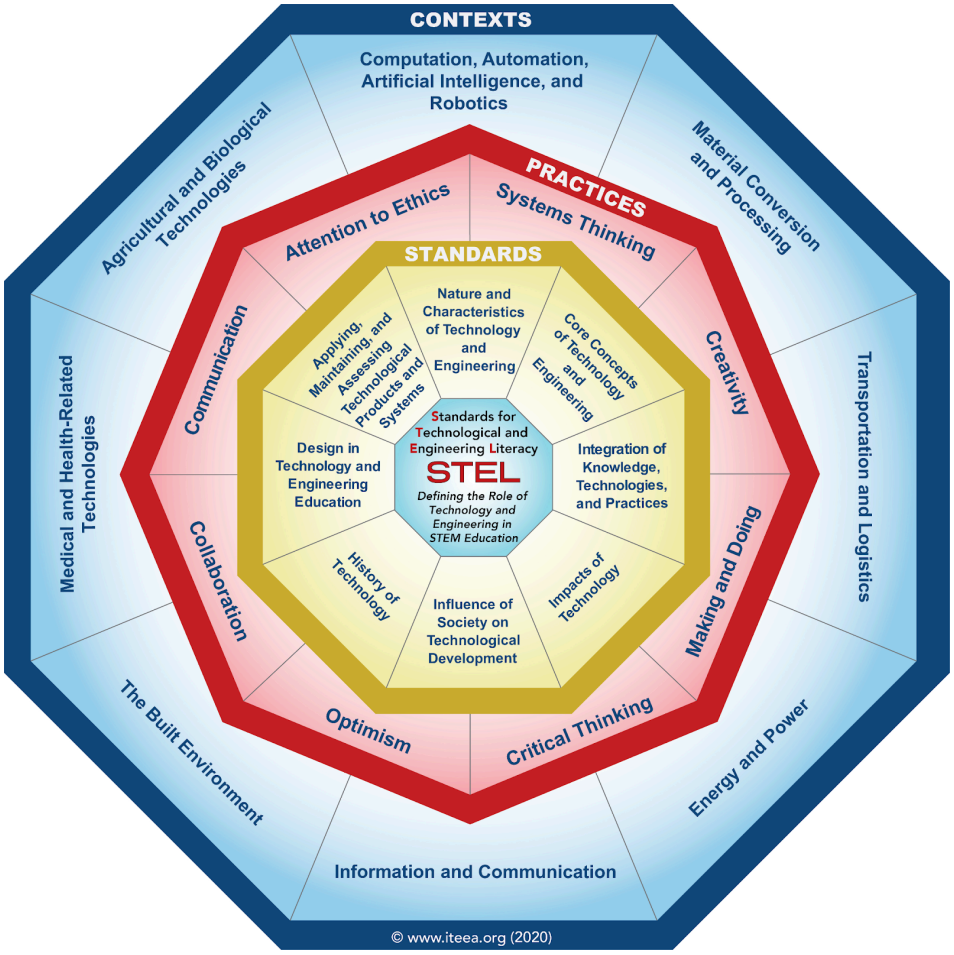


Figure 6. *Three Dimensions of STEL: Contexts, Practices, and Standards (ITEEA, 2020, p. 11)*

TEPs and Comparisons to CS Practices

STEL defines eight TEPs (ITEEA, 2020, pp. 14–15):

1. *Systems thinking:* a holistic understanding that all technologies are composed of interconnected parts and that they are embedded within larger systems
2. *Creativity*: the use of investigation, imagination, innovative thinking, and physical skills to accomplish goals, including design goals
3. *Making and doing:* design and build technological products and systems
4. *Critical thinking:* logical thinking, reasoning, and questioning in the process of making informed decisions
5. *Optimism:* having a belief that technologies can be improved and a commitment to finding better solutions to design challenges through experimentation, modeling, and adaptation

6. *Collaboration:* having the perspectives, willingness, and capabilities to work as part of a team in which all members' inputs are valued

7. *Communication:* a tool used to understand the wants and needs of the intended users or the community and a means to explain and defend choices made in the design process

8. *Attention to ethics*: focusing on the impact of technological products, systems, and processes on others and the environment

The TEPs are based on the six engineering habits of mind[3] described by the National Academy of Engineering (Centre for Real-World Learning, 2014) and the Learning and Innovation Skills[4] described by the Partnership for 21st Century Skills (2009). The STEL describes each of the TEPs in further detail and provides examples of how each practice has been implemented with students, but does not provide any performance benchmarks for the practices.

The TEPs overlap significantly with the CS practices in the *K–12 Computer Science Framework* and the 2017 CSTA K–12 CS Standards. TEP4, making and doing, aligns with CS practice 5, creating computational artifacts. TEP5, optimism, aligns with CS practice 6, testing and refining computational artifacts. TEP6, collaboration and TEP7, communication, align with CS practices 2 and 6, respectively.

The TEPs also have significant overlap with the Pillars and Dispositions in the *Reimagining CS Pathways* report. TEP2, creativity, and TEP4, critical thinking, are both Dispositions. TEP6, collaboration, and TEP8, attention to ethics, are both reflected in Pillars.

Content and Grade-Level Organization of the STEL

There are eight core disciplinary standards in the STEL:

1. Nature and characteristics of technology and engineering
2. Core concepts of technology and engineering
3. Integration of knowledge, technologies, and practices
4. Impacts of technology
5. Influence of society on technological development
6. History of technology
7. Design in technology and engineering education
8. Applying, maintaining, and assessing technological products and systems

These standards reflect the core knowledge, skills, and dispositions of technology and engineering that apply regardless of context. Although the STEL authors refer to these categories of core disciplinary knowledge as "standards," they are more akin to the topic areas or domains used in the standards and frameworks we have previously reviewed. The STEL explains the intent and key ideas behind each standard in narrative form, in approximately two pages. Table 27 lists the key ideas for each standard.

[3] 1) Systems thinking, 2) Creativity, 3) Optimism, 4) Collaboration, 5) Communication, and 6) Attention to ethical considerations

[4] 1) Creativity and innovation, 2) Critical thinking and problem solving, 3) Communication, and 4) Collaboration

Table 27. *STEL Standards and Key Ideas*

STEL Standard		Key Ideas
1	Nature and characteristics of technology and engineering	1. The study of technology and engineering requires knowledge of the natural world and the human-made world 2. The study of technology and engineering as a human activity is interdisciplinary 3. The study of technology and engineering involves the ability to understand, use, assess, and create technological products, systems, and ways of thinking
2	Core concepts of technology and engineering	1. A system is a group of interrelated components designed collectively to achieve a desired goal 2. Basic technology and engineering resources (or inputs) include tools and machines, materials, capital, money, knowledge, energy, time, and most importantly, people 3. Requirements are the expected outcomes of a completed product or system and present the designer with limitations, criteria, constraints, and opportunities during the development process 4. Trade-offs encompass a choice or exchange of one quality (or requirement) over another 5. Optimization is a process or methodology of designing or making a product, process, or system to the point at which it is the most fully functional and effective 6. A process is a systematic sequence of actions used to produce an output 7. Controls are the mechanisms or activities that apply information to cause systems to behave in desired ways
3	Integration of knowledge, technologies, and practices	1. Technology and engineering are interdisciplinary, relating to more than one content area 2. Technology and engineering impact, and are impacted by, technology transfer with other fields 3. Technology and engineering knowledge and practices advance and are advanced by other fields
4	Impacts of technology	1. Technology and engineering have both positive and negative impacts on society and the environment 2. Decisions made about technology and engineering involve consideration of costs, benefits, and trade-offs 3. Responsible creation and use of technology requires the sustainable use of renewable and nonrenewable resources and handling of waste 4. Use of technology can lead to fundamental changes in individuals, in human cultures, and in the environment

STEL Standard		Key Ideas
5	Influence of society on technological development	1. The needs and wants of society often shape technology and engineering more than individual needs and wants 2. The values and beliefs of societies shape attitudes toward technology 3. Societies are at different stages of development, which affects the diffusion of technological innovation
6	History of technology	1. Technological knowledge accelerated along with other fields of endeavor during the Renaissance 2. Historical eras are often defined by technological advancements 3. The history of technology chronicles positive and negative aspects of humanity
7	Design in technology and engineering education	1. Design is a fundamental human activity 2. There is often no single, correct solution in technology and engineering design; furthermore, designs can always be improved and refined 3. Design in technology and engineering is iterative 4. There is a range of skills needed to carry out technology and engineering design 5. There are universal principles and elements of design 6. Making is an inherent part of technology and engineering design 7. Design optimization is governed by criteria and constraints
8	Applying, maintaining, and assessing technological products and systems	1. Technologically literate people are better equipped to learn about and use technological products and systems than those individuals who lack prior technological experience 2. Maintenance of a technological product, system, or process is crucial to keeping it in proper working order, and when malfunctions do occur, appropriate repair is necessary 3. People should gather, synthesize, and analyze information before drawing conclusions when assessing a technological product, system, or process

Following the overall narrative describing each standard, there is a brief (several paragraphs) description of the standard for each grade band: PreK–2, 3–5, 6–8, and 9–12. Following each grade band overview, there is a series of benchmarks for students' knowledge and skills in order to meet the standard in that grade band. These benchmarks are most analogous to the standards and performance expectations in the 2017 CSTA K–12 CS Standards, the CCSS, and the NGSS. Table 28 shows how related benchmarks for Standard 4: Impacts of Technology progress across the grade bands. Table 29 shows the number of benchmarks for each standard in each grade band.

Table 28. *Example Benchmarks for STEL Standard 4 by Grade Band*

Grade Band	Example Benchmark
PreK–2	**STEL-4B. Illustrate helpful and harmful effects of technology.** Children can examine a familiar technology and explain how it can be both helpful and harmful. For example, a crayon can be used to draw creatively but can also be used to write on bedroom walls.
3–5	**STEL-4F. Describe the helpful and harmful effects of technology.** Students can begin to explore more fully the idea of intended, unintended, positive, and negative outcomes inherent in technologies. Students at this age learn how their own lives have been impacted through technology and how technological processes generate undesirable waste and emissions.
6–8	**STEL-4K. Examine the ways that technology can have both positive and negative effects at the same time.** The form and function of technologies are shaped by the criteria considered when the technology is developed. Even beneficial and well-intentioned solutions can have negative impacts. For example, flush toilets led to improved health and hygiene; at the same time, they created a need for water treatment strategies that consume large amounts of energy and fresh water. This type of example provides students an opportunity to consider the importance of design criteria.
9–12	**STEL-4P. Evaluate ways that technology can impact individuals, society, and the environment.** A variety of approaches and resources can be used by students when asked to evaluate given technologies. These include technology assessment, cost-benefit analysis, risk assessment, environmental impact analysis, and case studies, among others. By applying evaluative techniques, students can analyze the relationships between resources and technology to improve sustainability efforts. This process should be accompanied by an understanding of the importance of evaluating technologies in a holistic manner.

Table 29. *Number of STEL Standard Benchmarks by Grade Band*

STEL Standard		PreK–2	3–5	6–8	9–12	Total
1	Nature and characteristics of technology and engineering	4	5	4	5	18
2	Core concepts of technology and engineering	5	7	7	7	26
3	Integration of knowledge, technologies, and practices	2	2	3	3	10
4	Impacts of technology	5	5	5	5	20
5	Influence of society on technological development	3	2	2	3	10
6	History of technology	1	1	3	5	10
7	Design in technology and engineering education	7	8	7	8	30
8	Applying, maintaining, and assessing technological products and systems	3	4	6	5	18
Total # benchmarks per grade band		30	34	37	41	142

Technology and Engineering Contexts and Connections to Computer Science

Both Standard 4: Impacts of technology and Standard 5: Influence of society on technological development have strong connections to the Impacts and Ethics Pillar as described in the *Reimagining CS Pathways* report. We describe these connections further in the recommendations for Impacts and Ethics section.

STEL describes eight technology and engineering contexts to represent the breadth of technological activity:

1. Computing, automation, artificial intelligence, and robotics
2. Material conversion and processing
3. Transportation and logistics
4. Energy and power
5. Information and communication
6. The built environment
7. Medical and health-related technologies
8. Agricultural and biological technologies

These contexts provide opportunities for students to learn the knowledge, skills, and dispositions in the core disciplinary standards and to apply the TEPs. For each of the technology and engineering contexts, the STEL provides examples of instructional activities that integrate standards with practices in each grade band. These examples are not intended to reflect comprehensive coverage of any given standard.

The two contexts most closely related to CS are: 1) computing, automation, artificial intelligence, and robotics, and 2) information and communication. None of the example instructional activities involve programming, but there are many examples related to designing products, evaluating product designs, and optimizing products.

Arts and Humanities Standards and Frameworks

Common Core State Standards for English Language Arts

Content and Grade-Level Organization of the CCSSELA

The CCSSELA are anchored by four sets of College and Career Readiness (CCR) standards, which define "general, cross-disciplinary literacy expectations" for all students to be college and career ready (CCSSO, 2010a, p. 4). There are CCR standards for reading, writing, speaking and listening, and language. Table 30 shows all the anchor CCR standards in the CCSSELA.

In grades K–5, there are standards and substandards for each individual grade that define what students should understand and be able to do to develop their literacy in each of the areas defined by the CCR anchor standards. The CCSSELA indicate that since students typically receive most or all of their instruction from the same teacher, the K–5 standards address reading (literature and informational text), writing, speaking, and listening across the curriculum.

For grades 6–12, there is one set of standards and substandards for ELA and one for history/social studies, science, and technical subjects to reflect that all teachers have a role in developing students' literacy. The 6–12 standards for ELA are written for grades 6, 7, and 8 individually, then the 9–10 and 11–12 grade bands address all four sets of anchor CCR standards. The 6–12 standards for history/social studies, science, and technical subjects are written for the 6–8, 9–10, and 11–12 grade bands and address the anchor CCR standards for reading and writing. These standards are intended to supplement or be incorporated into content standards in these subject areas (CCSSO, 2010a). Table 31 shows the number of standards and substandards per grade/grade band.

Table 30. *Anchor CCR Standards in the CCSSELA*

Reading	Writing
Key ideas and details 1. Read closely to determine what the text says explicitly and to make logical inferences from it; cite specific textual evidence when writing or speaking to support conclusions drawn from the text. 2. Determine central ideas or themes of a text and analyze their development; summarize the key supporting details and ideas. 3. Analyze how and why individuals, events, and ideas develop and interact over the course of a text. *Craft and structure* 4. Interpret words and phrases as they are used in a text, including determining technical, connotative, and figurative meanings, and analyze how specific word choices shape meaning or tone. 5. Analyze the structure of texts, including how specific sentences, paragraphs, and larger portions of the text (e.g., a section, chapter, scene, or stanza) relate to each other and the whole. 6. Assess how point of view or purpose shapes the content and style of a text. *Integration of knowledge and ideas* 7. Integrate and evaluate content presented in diverse media and formats, including visually and quantitatively, as well as in words. 8. Delineate and evaluate the argument and specific claims in a text, including the validity of the reasoning as well as the relevance and sufficiency of the evidence. 9. Analyze how two or more texts address similar themes or topics in order to build knowledge or to compare the approaches the authors take. *Range of reading and level of text complexity* 10. Read and comprehend complex literary and informational texts independently and proficiently.	*Text types and purposes* 1. Write arguments to support claims in an analysis of substantive topics or texts using valid reasoning and relevant and sufficient evidence. 2. Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately through the effective selection, organization, and analysis of content. 3. Write narratives to develop real or imagined experiences or events using effective technique, well-chosen details and well-structured event sequences. *Production and distribution of writing* 4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. 5. Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach. 6. Use technology, including the Internet, to produce and publish writing and to interact and collaborate with others. *Research to build and present knowledge* 7. Conduct short as well as more sustained research projects based on focused questions, demonstrating understanding of the subject under investigation. 8. Gather relevant information from multiple print and digital sources, assess the credibility and accuracy of each source, and integrate the information while avoiding plagiarism. 9. Draw evidence from literary or informational texts to support analysis, reflection, and research. *Range of writing* 10. Write routinely over extended time frames (time for research, reflection, and revision) and shorter time frames (a single sitting or a day or two) for a range of tasks, purposes, and audiences.

Speaking and Listening	Language
Comprehension and collaboration 1. Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively. 2. Integrate and evaluate information presented in diverse media and formats, including visually, quantitatively, and orally. 3. Evaluate a speaker's point of view, reasoning, and use of evidence and rhetoric. *Presentation of knowledge and ideas* 4. Present information, findings, and supporting evidence such that listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose, and audience. 5. Make strategic use of digital media and visual displays of data to express information and enhance understanding of presentations. 6. Adapt speech to a variety of contexts and communicative tasks, demonstrating command of formal English when indicated or appropriate.	*Conventions of standard English* 1. Demonstrate command of the conventions of standard English grammar and usage when writing or speaking. 2. Demonstrate command of the conventions of standard English capitalization, punctuation, and spelling when writing. *Knowledge of language* 3. Apply knowledge of language to understand how language functions in different contexts, to make effective choices for meaning of style, and to comprehend more fully when reading or listening. *Vocabulary acquisition and use* 4. Determine or clarify the meaning of unknown and multiple-meaning words and phrases by using context clues, analyzing meaningful word parts, and consulting general and specialized reference materials, as appropriate. 5. Demonstrate understanding of figurative language, word relationships, and nuances in word meanings. 6. Acquire and use accurately a range of general academic and domain-specific words and phrases sufficient for reading, writing, speaking, and listening at the college and career readiness level; demonstrate independence in gathering vocabulary knowledge when encountering an unknown term important to comprehension or expression.

Connections to CS Content

The ELA standards have strong relevance to CS content, especially the standards about reading informational text and the additional reading and writing standards intended for teachers of science and technical subjects. In general, students should graduate high school with the ability to consume and comprehend text and other media about CS, to write about CS, and to discuss CS topics with others. The recommendations for Data and Analysis include reading, writing, and speaking as part of understanding, conducting, and evaluating statistical investigations. Similarly, the recommendations for computational thinking and human-centered design include connections to ELA for identifying and documenting program requirements, program development, and program impacts.

The Impacts and Ethics Pillar from the *Reimagining CS Pathways* report presents the richest connections between CS and ELA.

Table 31. *Number of CCR Anchor Standards by Grade*

CCR Anchor Standards		K	1	2	3	4	5	6	7	8	9–10	11–12
Reading	Foundational Skills	17	19	11	9	6	6	-	-	-	-	-
	Literature	9	9	9	9	9	9	9	9	9	9	9
	Informational Text	10	10	10	10	10	10	10	10	10	10	10
	History/Social Studies	-	-	-	-	-	-	10			10	10
	Science & Technical Subjects	-	-	-	-	-	-	10			10	10
Writing	General	7	7	7	21	26	26	28	28	28	28	28
	History/Social Studies; Science & Technical Subjects	-	-	-	-	-	-	20			20	19
Speaking and Listening		8	9	9	10	10	10	10	10	10	10	10
Language		21	26	25	31	26	24	22	19	21	18	17
Total # standards for ELA		72	80	71	90	87	85	79	76	78	75	74
Total # standards for other subjects		-	-	-	-	-	-	40			40	39

National Curriculum Standards for Social Studies

The National Curriculum Standards for Social Studies were developed by the National Council for the Social Studies (NCSS) in 2010. These standards provide "the essential conceptual framework for curriculum design and development to prepare informed and active citizens" (NCSS, 2010, p. 11).

Content and Organization of the National Curriculum Standards for Social Studies

The National Curriculum Standards for Social Studies are organized around 10 themes (NCSS, 2010, pp. 3–4):

1. **Culture.** Through the study of culture and cultural diversity, learners understand how human beings create, learn, share, and adapt to culture, and appreciate the role of culture in shaping their lives and society, as well as the lives and societies of others.

2. **Time, continuity, and change.** Through the study of the past and its legacy, learners examine the institutions, values, and beliefs of people in the past, acquire skills in historical inquiry and interpretation, and gain an understanding of how important historical events and developments have shaped the modern world.

3. **People, places, and environments.** This theme helps learners to develop their spatial views and perspectives of the world, to understand where people, places, and resources

are located and why they are there, and to explore the relationship between human beings and the environment.

4. **Individual development and identity.** Personal identity is shaped by family, peers, culture, and institutional influences.
5. **Individuals, groups, and institutions.** Institutions such as families and civic, educational, governmental, and religious organizations, exert a major influence on people's lives.
6. **Power, authority, and governance.** One essential component of education for citizenship is an understanding of historical development and contemporary forms of power, authority, and governance.
7. **Production, distribution, and consumption.** This theme provides for the study of how people organize for the production, distribution, and consumption of goods and services, and prepares students for the study of domestic and global economic issues.
8. **Science, technology, and society.** By exploring the relationships among science, technology, and society, students develop an understanding of past and present advances in science and technology and their impact.
9. **Global connections.** The realities of global interdependence require an understanding of the increasingly important and diverse global connections among world societies.
10. **Civic ideals and practices.** An understanding of civic ideals and practices is critical to full participation in society and is an essential component of education for citizenship.

For each theme, there is a set of learning expectations for the early grades (preK–4), middle grades (5–8), and high school (9–12). Learning expectations for each grade band are broken down into four components:

- Questions for exploration
- Knowledge ("learners will understand…")
- Processes ("learners will be able to…")
- Products ("learners will demonstrate understanding by…")

For each theme and grade band, the National Curriculum Standards for Social Studies also includes two "snapshots of practice": examples of how instructors have implemented the standards.

The Appendices to the standards describe essential social studies skills (literacy and critical thinking skills), strategies (research-based literacy strategies for teachers, learning strategies for students, and personal interaction and civic engagement strategies), and democratic beliefs and values which should be emphasized in social studies curriculum.

Connections to CS Content

Theme 8: Science, technology, and society, is strongly connected to the Impacts and Ethics Pillar described in the *Reimagining CS Pathways* report. We describe these connections further in the recommendations for Impacts and Ethics section.

National Core Arts Standards

The National Core Arts Standards are meant to "guide arts curriculum, instruction, and assessment in America's schools" (National Coalition for Core Arts Standards, n.d., p. 6). The revised arts standards have been adopted by 40 states and the Department of Defense.

Content and Organization of the National Core Arts Standards

The National Core Arts Standards are a set of art standards that include four artistic processes (Creating, Performing/Presenting/Producing, Responding, Connecting) and 11 anchor standards. Table 32 shows the process and anchor standards.

Table 32. *National Core Arts Standards—Artistic Processes and Anchor Standards (National Coalition for Core Arts Standards, n.d., p. 13)*

National Core Arts Standards			
Artistic Processes			
Creating: Conceiving and developing new artistic ideas and work.	**Performing/Presenting/ Producing**: *Performing*: Realizing artistic ideas and work through interpretation and presentation. *Presenting*: Interpreting and sharing artistic work. *Producing*: Realizing and presenting artistic ideas and work	**Responding**: Understanding and evaluating how the arts convey meaning	**Connecting:** Relating artistic ideas and work with personal meaning and external context.
Anchor Standards			
Students will: 1. Generate and conceptualize artistic ideas and work. 2. Organize and develop artistic ideas and work. 3. Refine and complete artistic work.	Students will: 4. Select, analyze, and interpret artistic work for presentation. 5. Develop and refine artistic techniques and work for presentation. 6. Convey meaning through the presentation of artistic work.	Students will: 7. Perceive and analyze artistic work. 8. Interpret intent and meaning in artistic work. 9. Apply criteria to evaluate artistic work.	Students will: 10. Synthesize and relate knowledge and personal experiences to make art. 11. Relate artistic ideas and works with societal, cultural, and historical context to deepen understanding.

The standards include the anchor standards, enduring understandings, essential questions, and articulations of student achievement. Enduring understandings cover ideas and processes central to a discipline (e.g., dance) and essential questions "guide students as they uncover enduring understandings" (National Coalition for Core Arts Standards, n.d., p. 14). For grades PK–8, the standards articulate student achievement in each grade level. For grades 9–12, the standards are presented in proficiency levels (Proficient, Accomplished, and Advanced).

Connections to CS Content

While there are not strong connections between the National Core Arts Standards and CS content, there are areas of overlap between the two. These areas include general problem-solving skills (e.g., TH:Cr.1.1.7.a Investigate multiple perspectives and solutions to staging challenges in a drama/theatre work), abstraction (e.g., DA:Re.7.1.2 Find movements in a dance that develop a pattern.), and communication (e.g., MU:Pr4.I.T.Ia Develop and explain the criteria used for selecting a varied repertoire of music based on interest, music reading skills, and an understanding of the performer's technical and technological skill). Additionally, technology is used in the disciplines. The Dispositions in the *Reimagining CS Pathways* report offer connections between art and CS content.

The Common Career Technical Core

The Common Career Technical Core (CCTC) is an initiative led by 42 states, the District of Columbia, and Palau. The CCTC is a set of standards focused on the knowledge and skills CTE students need to be successful. The CCTC was released in 2012, and it is currently unclear how many states have chosen to adopt the standards. The standards include Career Ready Practices, which are career skills all students will need, regardless of their discipline. The CCTC includes 16 Career Clusters and 79 Career Pathways under those clusters.

Career Ready Practices and Comparisons to CS Practices

The CCTC contains 12 Career Ready Practices, which are meant to be taught in all programs. The practices should become more complex and expectations should increase as the student becomes more advanced. Table 33 lists the Career Ready Practices and their descriptions.

Content and Organization of the CCTC

The CCTC are organized into 16 Career Clusters and their corresponding Career Pathways:

- Agriculture, Food & Natural Resources Career Cluster™ (AG)
- Architecture & Construction Career Cluster™ (AC)
- Arts, A/V Technology & Communications Career Cluster™ (AR)
- Business Management & Administration Career Cluster™ (BM)
- Education & Training Career Cluster™ (ED)
- Finance Career Cluster™ (FN)
- Government & Public Administration Career Cluster™ (GV)
- Health Science Career Cluster™ (HL)
- Hospitality & Tourism Career Cluster™ (HT)
- Human Services Career Cluster™ (HU)
- Information Technology Career Cluster™ (IT)
- Law, Public Safety, Corrections & Security Career Cluster™ (LW)
- Manufacturing Career Cluster™ (MN)
- Marketing Career Cluster™ (MK)
- Science, Technology, Engineering & Mathematics Career Cluster™ (ST)
- Transportation, Distribution & Logistics Career Cluster™ (TD)

Table 33. *CCTC Practices and Descriptions (National Association of State Directors of Career Technical Education Consortium/National Career Technical Education Foundation, 2012)*

Career Ready Practice	Description
1. Act as a responsible and contributing citizen and employee.	Understand the obligations and responsibilities of being a member of a community, and they demonstrate this understanding every day through their interactions with others.
2. Apply appropriate academic and technical skills.	Readily access and use the knowledge and skills acquired through experience and education to be more productive. Make connections between abstract concepts with real-world applications.
3. Attend to personal health and financial well-being.	Understand the relationship between personal health, workplace performance and personal well-being; act on that understanding to regularly practice healthy diet, exercise and mental health activities.
4. Communicate clearly, effectively and with reason.	Communicate thoughts, ideas and action plans with clarity, whether using written, verbal and/or visual methods.
5. Consider the environmental, social and economic impacts of decisions.	Understand the interrelated nature of their actions and regularly make decisions that positively impact and/or mitigate negative impact on other people, organizations and the environment.
6. Demonstrate creativity and innovation.	Regularly think of ideas that solve problems in new and different ways, and they contribute those ideas in a useful and productive manner to improve their organization.
7. Employ valid and reliable research strategies.	Discerning in accepting and using new information to make decisions, change practices or inform strategies. Use a reliable research process to search for new information.
8. Utilize critical thinking to make sense of problems and persevere in solving them.	Readily recognize problems in the workplace, understand the nature of the problem, and devise effective plans to solve the problem.
9. Model integrity, ethical leadership and effective management.	Consistently act in ways that align to personal and community-held ideals and principles while employing strategies to positively influence others in the workplace. Have a clear understanding of integrity and act on this understanding in every decision.
10. Plan education and career path aligned to personal goals.	Take personal ownership of their own educational and career goals, and they regularly act on a plan to attain these goals.
11. Use technology to enhance productivity.	Find and maximize the productive value of existing and new technology to accomplish workplace tasks and solve workplace problems. Flexible and adaptive in acquiring and using new technology.
12. Work productively in teams while using cultural/global competence.	Positively contribute to every team whether formal or informal. They apply an awareness of cultural differences to avoid barriers to productive and positive interaction.

Connections to Computer Science

Table 34 displays which Career Pathways and their corresponding Career Clusters are most relevant to the topic areas in the *Reimagining CS Pathways* report. The relevant topic areas are Algorithms, Programming, Computing Systems and Security, and Preparation for the Future.

Table 34. *CCTS Career Clusters and Career Pathways Relevant to CS*

Career Cluster	Career Pathway	*Reimagining CS Pathways*
Information Technology Career Cluster™ (IT)	Information Support & Services Career Pathway (IT-SUP) Network Systems Career Pathway (IT-NET) Programming & Software Development Career Pathway (IT-PRG) Web & Digital Communications Career Pathway (IT-WD)	Algorithms Programming Computing Systems and Security Preparation for the Future
Science, Technology, Engineering & Mathematics Career Cluster (ST)	Engineering & Technology Career Pathway (ST-ET)	Algorithms Preparation for the Future

Social Justice Standards

The Social Justice Standards were developed for teachers and administrators to use while developing curriculum and to ensure that schools are "more just, equitable and safe" (Learning for Justice, n.d., p. 2). The standards were published in 2016 and include anchor standards and learning outcomes. The standards are arranged into four domains: Identity, Diversity, Justice, and Action (IDJA). Table 35 shows the anchor standards and domains.

Table 35. *Social Justice Anchor Standards by Domain (*Learning for Justice, n.d., *p. 3)*

Identity	Diversity	Justice	Action
1. Students will develop positive social identities based on their membership in multiple groups in society.	6. Students will express comfort with people who are both similar to and different from them and engage respectfully with all people.	11. Students will recognize stereotypes and relate to people as individuals rather than representatives of groups.	16. Students will express empathy when people are excluded or mistreated because of their identities and concern when they themselves experience bias.
2. Students will develop language and historical and cultural knowledge that affirm and accurately describe their membership in multiple identity groups.	7. Students will develop language and knowledge to accurately and respectfully describe how people (including themselves) are both similar to and different from each other and others in their identity groups.	12. Students will recognize unfairness on the individual level (e.g., biased speech) and injustice at the institutional or systemic level (e.g., discrimination).	17. Students will recognize their own responsibility to stand up to exclusion, prejudice and injustice.
3. Students will recognize that people's multiple identities interact and create unique and complex individuals.	8. Students will respectfully express curiosity about the history and lived experiences of others and will exchange ideas and beliefs in an open-minded way.	13. Students will analyze the harmful impact of bias and injustice on the world, historically and today.	18. Students will speak up with courage and respect when they or someone else has been hurt or wronged by bias.
4. Students will express pride, confidence and healthy self-esteem without denying the value and dignity of other people.	9. Students will respond to diversity by building empathy, respect, understanding and connection.	14. Students will recognize that power and privilege influence relationships on interpersonal, intergroup and institutional levels and consider how they have been affected by those dynamics.	19. Students will make principled decisions about when and how to take a stand against bias and injustice in their everyday lives and will do so despite negative peer or group pressure.
5. Students will recognize traits of the dominant culture, their home culture and other cultures and understand how they negotiate their own identity in multiple spaces.	10. Students will examine diversity in social, cultural, political and historical contexts rather than in ways that are superficial or oversimplified.	15. Students will identify figures, groups, events and a variety of strategies and philosophies relevant to the history of social justice around the world.	20. Students will plan and carry out collective action against bias and injustice in the world and will evaluate what strategies are most effective.

Content and Grade-Level Organization of the Social Justice Standards

Each anchor standard includes grade band–level outcomes for four grade bands: K–2, 3–5, 6–8, 9–12. The standards also include anti-bias scenarios "to show what anti-bias attitudes and behavior may look like in the classroom" (Learning for Justice, n.d., p. 2). Table 36 contains an example of the 9–12 grade-level outcomes for the Identity anchor standards and the anti-bias scenario that is included.

Table 36. *Example of 9–12 Grade-Level Outcomes for the Identity Anchor Standards (*Learning for Justice, n.d., *p. 10)*

Anchor Standard	Code	Grade-Level Outcome	Anti-Bias Scenario
Identity 1	ID.9-12.1	I have a positive view of myself, including an awareness of and comfort with my membership in multiple groups in society.	As part of a class project, Rebecca completes the following personal mission statement: "I am more than one identity. I celebrate all of who I am. The way my identities overlap have made me who I am today. I cannot separate the parts of myself. I will not allow others to put me into boxes." Rebecca explains to her peers in small group discussion that her identities as a student, sister, Cherokee, queer, athlete and Tsalagi speaking person are all interconnected and are all important to her. She displays her personal mission statement on the outside of her class binder.
Identity 2	ID.9-12.2	I know my family history and cultural background and can describe how my own identity is informed and shaped by my membership in multiple identity groups.	
Identity 3	ID.9-12.3	I know that all my group identities and the intersection of those identities create unique aspects of who I am and that this is true for other people too.	
Identity 4	ID.9-12.4	I express pride and confidence in my identity without perceiving or treating anyone else as inferior.	
Identity 5	ID.9-12.5	I recognize traits of the dominant culture, my home culture and other cultures, and I am conscious of how I express my identity as I move between those spaces.	

Connections to CS Content

While there are not strong connections between the Social Justice Standards and CS content, there are areas of overlap between the two. In particular, the Social Justice Standards' anchor standards include recognizing unfairness/bias, and communicating in culturally appropriate ways. The Impacts and Ethics and Inclusive Collaboration Pillars from the *Reimagining CS Pathways* report offer the closest connections between the Social Justice Standards and CS content.

Additional Resources

The California Computer Science Standards, which are based on and closely align to the CSTA standards, contain crosswalks to highlight connections between the CSTA standards and practices and those of other disciplines, including the CCSS for Mathematics and ELA; the NGSS; and California's adopted standards for history and social studies, visual performing arts, and career technical education (CDE, 2021, pp. 173–226). These crosswalks list practice-to-practice and standard-to-standard connections and may be valuable for CSTA's standards writers.

Recommendations for Standards Writers

The recommendations for standards writers in this section focus on areas where the CS standards overlap with the standards and frameworks reviewed here. Thus, we do not address recommendations for the Algorithms and Programming topic areas, which are CS-specific.

Standards Structure

Grade-Level/Grade-Band Structure

Table 37 shows the grade-level/grade-band structure for each of the standards and frameworks we reviewed in this report.

Table 37. *Comparison of Grade-Level/Grade-Band Structures*

Standards/Framework	PreK	K	1	2	3	4	5	6	7	8	9–10	11–12
CS-Specific Standards and Frameworks												
K–12 CS Framework	N/A	■■■			■■■			■■■			■■■■	
2017 K–12 CS Standards	N/A	■■■			■■■			■■■			■■	■■
EU Informatics Ref. Framework	Primary, lower secondary, upper secondary											
AI4K12	N/A	■■■			■■■			■■■			■■■■	
K–12 Cybersec. Learning Stds.	N/A	■■■			■■■			■■■			■■■■	
Other STEM Standards and Frameworks												
CCSS—Math	N/A	■	■	■	■	■	■	■	■	■	■■■■	
GAISE II	Levels A, B, and C; no grade-specific instructional recommendations											
NGSS	N/A	■	■	■	■	■	■	■■■			■■■■	
STEL	■■■■				■■■			■■■			■■■■	
Arts and Humanities Standards and Frameworks												
CCSS—ELA	N/A	■	■	■	■	■	■	■	■	■	■■	■■
Nat'l Curr. Stds. for Soc. Stud.	■■■■■■							■■■■			■■■■	
National Core Arts Stds.	■	■	■	■	■	■	■	■	■	■	■■■■	
Common Career Tech. Core	N/A	■■■■■■■■■■■■■										
Social Justice Standards	N/A	■■■			■■■			■■■			■■■■	

Based on the frequency of different types of structures, we recommend the following for the revised CS standards:

- **Pre-K standards should be included as part of a grade band (e.g., PreK–2), if they are included at all.** Most of the standards and frameworks did not include pre-K, perhaps because very few states even offer universal pre-K, and no states have compulsory pre-K enrollment (Alawsaj et al., 2023).
- **Elementary school standards (grades K–5) can be written for individual grades or for two grade bands: K–2 and 3–5.** It was more common for standards and frameworks to have standards for two elementary grade bands (K–2 and 3–5). All of the CS-specific standards and frameworks used this structure. The CCSS and NGSS, which are written for subjects that have federally mandated standardized testing, all had individual grade-level standards for K–5. We think either structure for K–5 standards is defensible.
- **Middle school standards (grades 6–8) should be banded together.** Only the CCSS and the National Core Arts standards define individual grade-level standards for middle school. The CCSS subject areas, Math and ELA, are the only subjects that have federally mandated standardized testing in every year from grades 3–8. Thus we recommend a single set of standards for the 6–8 grade band.
- **High school standards (grades 9–12) should be banded together.** This is by far the most common structure for high school standards, due to the variability and flexibility that high schools offer for course sequences in different subjects. Only the 2017 K–12 CS Standards and the CCSSELA have multiple grade bands within high school; no standards and frameworks have standards for individual high school grades.

Length of Standards

Standards should generally be one sentence of around 20 words, with one verb.

To better understand the structure of the standards themselves, we randomly sampled 10 standards, each from the CCSSM and the NGSS (see Appendix B). We chose to sample from these standards documents because they are the most similar to the 2017 CSTA K–12 CS Standards, in that they are nationally known sets of STEM standards that have been adopted by states. With one exception, all of the sampled standards were one sentence long. With three exceptions, all from the NGSS, the sampled standards only contained one verb. The length of standards ranged from 10–44 words[5], with the median length being approximately 20 words for both CCSSM and NGSS.

Examples, clarifying statements, and assessment boundaries were more variable in length, ranging from 8–80 words. Only three of the 10 standards sampled from the CCSSM contained examples. The median length of the examples included with sampled CCSSM standards was 34 words. All of the standards sampled from the NGSS contained either a clarifying statement or an assessment boundary. The median length of the clarifying statements and assessment boundaries in the NGSS was 18 words.

[5] For the CCSSM standards, we counted entire expressions and equations as one word.

Number of Standards

Write 10–15 standards per grade level and aim for a total of 150–200 standards.

We compared the number of standards per grade for the STEM standards included in this report: the 2017 CSTA K–12 CS Standards, STEL, NGSS, and CCSSM (see Table 38).

There are only 120 standards in the 2017 CSTA K–12 CS Standards while the CCSSM has over four times that many: 510. Across all the sets of standards, the median number of standards per grade level ranged from 11–16, with the K–2 and 3–5 grade bands having fewer standards than the 6–8 and 9–12 grade bands.

We recommend writing additional CS standards for the revision, aiming for 150–200 standards, or 10–15 standards per grade level[6]. This is more than the 142 benchmarks in the STEL and less than the 210 performance expectations in the NGSS. We feel this is a justifiable target since, unlike the 2017 CS K–12 Standards, the STEL has not been formally adopted by any states while the NGSS is both formally adopted by states and, unlike CS, subject to federally-mandated standardized testing in K–12.

Table 38. *Comparison of Number of STEM Standards per Grade*

Standards	K–2	3–5	6–8	9–12	Total
2017 CSTA CS	18	21	23	58	120
STEL	30[7]	34	37	41	142
NGSS	37	46	61	66	210
CCSSM	77	114	127	192	510
Median # of Standards	33.5	40	49	62	176
...Per Grade Level	10.9	13.3	16.3	12.4	13.5

Variation in Structure

Consider varying the structure of the standards by grade bands or by topic areas.

The 2017 CSTA K–12 CS Standards are very uniform. For the most part, all concepts and subconcepts are addressed in every grade band, often with exactly one standard per subconcept/grade-band pair. In contrast, the CCSS for both Mathematics and ELA have variable structures to reflect different content needs for students in different grade bands, though this can create some challenges for curriculum and assessment development.

[6] Multiply the target number of standards per grade level by the number of grades in a grade band for the target number of standards in a grade band (e.g., the 9–12 grade band contains four grade levels, so there should be 40–60 standards).
[7] Includes Pre-K

Ways to vary the structure of the standards might include the following:

- For any given topic, write more standards for middle and high school than for elementary school.
- Include subtopics that have standards for only part of the K–12 progression.
    - *Example:* If the Data and Analysis topic area will include a subtopic about statistical analysis, it should begin in middle school, based on the progressions in the CCSSM.
- Provide alternative structures for content that is not tied to specific grade bands but that must be taught sequentially.
    - *Example:* Programming is a topic area where students need to progress through fundamentals of programming, such as variables and control structures, regardless of when they begin to program. Consider using a grade-independent level structure (e.g., introductory, intermediate, and advanced) or developing alternative sequences of standards for students who begin programming in different grade bands.

Integrating the Pillars

Adopt clear descriptions of the content and practices contained within each pillar.

The *Reimagining CS Pathways* report introduces Pillars, which function similarly to crosscutting concepts in the NGSS and are intended to be embedded within each Topic Area. The Pillars are intended to include key ideas and practices, methods, or approaches that are integral to each Topic Area. In this section, we expand upon the brief descriptions of the Pillars in the *Reimagining CS Pathways* report. A major goal of these expanded descriptions is to clearly identify a set of practices for each Pillar to promote shared language across standards and frameworks that can support integration (i.e., "Pillars" are unique to the *Reimagining CS Pathways* framing while "practices" appear in many standards and frameworks). Another major goal is to create explicit links between the Pillars and the practices and content described in the *K–12 Computer Science Framework* to facilitate continuity between the 2017 CSTA K–12 CS Standards and the revised standards.

Impacts and Ethics

The *Reimagining CS Pathways* report expects "a foundational course to spend a substantial amount of time on these issues, and to do so in a way that integrates these ideas with more technical topics so that students understand the interwoven relationships between technical considerations and societal and ethical implications" (CSTA et al., 2024, p. 12). **Thus, we recommend that Impacts and Ethics be a distinct subtopic within each of the Topic Areas.**

Impacts and Ethics is a Pillar that contains both key ideas (i.e., content) and practices. We recommend that the revised CS standards contain the following key ideas within Impacts and Ethics, which are adapted from STEL Standard #4, STEL TEP-8, and the National Curriculum Standards for Social Studies, as well as other content that fell under the Impacts of Computing Topic Area in the *K–12 Computer Science Framework* and the 2017 CSTA K–12 CS Standards (Appendix C).

1. Access to and use of computing technologies differs across groups of people (e.g., by socioeconomic status; geographic location; cultural background; differences in ability, gender, race, and ethnicity; and other social identities).

2. Computing has both positive and negative impacts on society and the environment.
    a. Over-optimism about computing technologies can lead to ethical challenges.
    b. Computing technologies impact people differently depending on their values, socioeconomic status, geographic location, cultural background, abilities, and social identities.
    c. There are laws to regulate the design and use of computing technologies, as well as unsuccessful attempts to enact such laws.

3. Responsible creation and use of computing technology requires consideration of ethical issues.
    a. Decisions made about the design and use of computing technologies involve consideration of costs, benefits, and trade-offs.
    b. Computing technology should be optimized to perform the task for which it was designed with the least possible harmful impacts on users and the environment.

We also recommend that Impacts and Ethics contain a single practice: *Apply ethical principles when developing or evaluating computational tools.* The below ethical principles are adapted from the Association for Computing Machinery's (ACM) list of general ethical principles (ACM, 2018):

1. Use computing for the public good.
    a. Acknowledge that all people hold an interest in computing.
    b. Respect diversity.
    c. Promote environmental sustainability of computing technologies.

2. Avoid harm caused by computing technologies, including physical or mental injury, unjustified destruction or disclosure of information, and unjustified damage to property, reputation, or the environment.
    a. Carefully consider the potential impacts of new computing technologies to avoid unintentionally causing harm.
    b. Undo or mitigate harm caused by computing technologies as much as possible.

3. Be honest and trustworthy.

4. Be fair and do not discriminate.
    a. Create computing technologies that are as inclusive and accessible as possible.
    b. Do not create technologies that disenfranchise or oppress people.

5. Respect the work required to produce new ideas, inventions, creative works, and computing artifacts (similar to Practice 7.3 from the *K–12 Computer Science Framework*).
    a. Only use others' work with permission.
    b. Give appropriate attribution to others' work.

6. Respect privacy.
    a. Protect data from unauthorized access and accidental disclosure.
    b. Only collect the minimum amount of information necessary.
    c. Clearly describe what data is being collected, how it is being stored and used, and when it will be disposed of.
    d. Do not use data collected for a specific purpose for another purpose without consent.

Inclusive Collaboration

Inclusive Collaboration is one of the priority areas identified in the *Reimagining CS Pathways* report. The core of this Pillar is "to engage with diverse perspectives with respect and empathy" (CSTA et al., 2024, p. 16). The *Reimagining CS Pathways* report provides two categories of skills that fall under Inclusive Collaboration: 1) Awareness of and empathy with others and 2) Collaboration skills. We have expanded upon these ideas by synthesizing related practices in the *K–12 Computer Science Framework*, the STEL, the Social Justice Standards, and the Framework for 21st Century Learning (Partnership for 21st Century Skills, 2009) to create three specific practices that fall under Inclusive Collaboration:

Communicate clearly, using oral, written, and nonverbal methods, and practice intercultural competence.

1. Know when to listen and when to speak.
2. Cultivate working relationships with individuals possessing diverse perspectives, skills, and personalities (K–12 CS Framework, 2016, Practice 2.1), and aim to build empathy, respect, understanding, and connection.
3. Express curiosity about the perspectives of others and exchange ideas in open-minded ways.
4. Leverage social and cultural differences to create new ideas, increase innovation, and improve the quality of work.

Actively manage projects and coordinate with others.

5. Establish common goals and team norms (K–12 CS Framework, 2016, Practice 2.2).
6. Leverage team members' strengths to accomplish common goals.
7. Define team roles and create equitable workloads (K–12 CS Framework, 2016, Practice 2.2).
8. Value the individual contributions of each team member.
9. Manage time effectively.
10. Document work products and processes (similar to K–12 CS Framework, 2016, Practice 7.2).

Act responsibly and demonstrate accountability to others.

11. Solicit and incorporate feedback from team members and other interested parties (K–12 CS Framework, 2016, Practice 2.3).
12. Participate actively and be reliable and punctual.
13. Assume shared responsibility for collaborative work.
14. Be flexible, helpful, and willing to make necessary compromises to accomplish a common goal.
15. Exhibit honesty and integrity.

Computational Thinking

In the *K–12 Computer Science Framework* and the 2017 CSTA K–12 CS Standards, computational thinking is expressed through a series of four practices. For the revised CS standards, we recommend dividing those practices across the Computational Thinking and Human-Centered Design Pillars and incorporating additional sub-practices to represent the breadth of computational thinking described in the *Reimagining CS Pathways* report as well as by Brennan and Resnick (2012). Our suggested new formulation of the Computational Thinking Pillar includes two practices with a total of eight sub-practices.

Make sense of problems, test, and troubleshoot.

1. Analyze computational problems, make conjectures about the sources of errors and possible solutions, and "plan a solution pathway rather than simply jumping into a solution attempt" (CCSSM, SMP1).
2. Systematically test computational artifacts by considering all scenarios and using test cases (K–12 CS Framework, 2016, Practice 6.1, p. 81).
3. Use systematic processes to identify and fix errors (adapted from K–12 CS Framework, 2016, Practice 6.1, p. 81).

Look for patterns, develop and use abstractions, and modularize.

4. Decompose complex problems into manageable subproblems that can integrate existing solutions or procedures (K–12 CS Framework, 2016, Practice 3.1, p. 77).
5. Look for patterns and repetition. Identify and create general methods for performing repetitive tasks (similar to CCSSM, SMP7 and SMP8).
6. Extract common features from a set of integrated processes or complex phenomena (K–12 CS Framework, 2016, Practice 4.1, p. 78).
7. Evaluate existing functional modules and incorporate them into new designs (K–12 CS Framework, 2016, Practice 4.2, p. 78).
8. Create modules and develop points of interaction between them that can apply to multiple situations to reduce complexity (K–12 CS Framework, 2016, Practice 4.3, p. 79).

Human-Centered Design

Due to the close relationship between programming and engineering, we recommend including a human-centered design subtopic in at least the Programming Topic Area which addresses several key ideas. The key ideas described below draw from a variety of well-known resources on human-centered design.

1. Human-centered design is "an approach to interactive systems that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility and sustainability; and counteracts possible adverse effects of use on human health, safety and performance" (NIST, 2021).

2. There are four principles of human-centered design (Interaction Design Foundation, n.d.a; Vinney, 2023):

    a. *Be people-centered.* In other words, "know your user." Understand and focus on their needs, abilities, and contexts.

    b. *Understand and solve the right problems: the root problems.* Distinguish between the root cause of a problem and the symptoms of a problem. Solve the underlying problem rather than addressing symptoms.

    c. Think of everything as a system of interconnected parts.

    d. *Start with small and simple interventions and iterate* rather than rushing into big design solutions. Continually prototype, test, and refine your solutions to make sure they meet people's needs.

3. Human-centered design is related to humanity-centered design, which focuses on designing systems that consider the entire ecosystem of people, all living things, and the environment (Interaction Design Foundation, n.d.b).

As noted above, three of the four existing CS practices map closely onto the Engineering design process outlined in the NGSS. We combine these practices and update them to reflect a human-centered engineering design cycle and to better align them with the NGSS.

Apply principles of human-centered design when creating computational artifacts.

1. Identify and define real-world problems that can be solved computationally (K–12 CS Framework, 2016, Practice 3.1), the people impacted by the problems, and any requirements of or constraints on the eventual solutions.

2. Design and develop computational solutions to real-world problems, "taking into account key features, time and resource constraints, and user expectations" (K–12 CS Framework, 2016, Practice 5.1). Begin by generating several possible solutions and evaluating them to see which one best meets the criteria for resource use and user experience.

3. Test, refine, and optimize computational solutions. Test the computational solutions with diverse users. Prioritize improvements to the most important features.

Integrating Practices

Explicitly integrate practices and content within the standards.

The CCSSM contains practices, but does not explicitly integrate the practices into the content standards, nor does it define performance expectations for the practices by grade or grade band. The NGSS and 2017 CSTA K–12 CS Standards, both more recently developed, do explicitly include the practices in the content standards. We recommend continuing this practice, identifying a specific practice or sub-practice, as defined above, for each content standard.

Inclusion of Additional Information

Standards should be accompanied by supplementary material.

Generally speaking, standards are descriptions of what students should know and be able to do after instruction. They should be written to allow for flexibility in instruction and assessment. The standards we reviewed varied in how much additional information they included. The CCSSM includes only the statement of what students should know and do while the NGSS includes references to disciplinary core ideas, practices, crosscutting concepts, and connections to other standards. Writers will have to decide how much additional content to include with each standard, but any additional content should be kept brief, similar to the length of the standard itself.

CCSSM and NGSS are both accompanied by copious amounts of material to help readers understand the standards and how they can be implemented and assessed. We recommend that the standards writers develop supplementary material similar to those included for other sets of standards, either as a separate document or as an introduction or appendices to the standards. At a minimum, we recommend material for each of the following:

- Defining the topic areas and the learning progression within each topic area
- Defining the Pillars and the learning progression within each Pillar
- Defining the dispositions and the learning progression within each disposition
- Connections to the CCSSM
- Connections to the NGSS

Computing Systems and Security

These learning outcomes for the Computing Systems and Security topic area in the *Reimagining CS Pathways* report are closely related to content from the K–12 Cybersecurity Learning Standards:

CS.1 Identify various types of hardware (including components) and software (including operating systems)

CS.2 List security practices (e.g., safe passwords, two-factor authentication)

CS.3 Explain what networks (including the Internet) are and how they work

CS.4 Explain how an operating system, other software, and hardware work together

CS.5 Describe why cybersecurity is important

CS.10 Describe vulnerabilities in networks

We have the following recommendations for the revised CS standards in Computing Systems and Security based on overlaps between the K–12 Cybersecurity Learning and CSTA K–12 CS Standards (Appendix D) and topics that were exclusively covered in the K–12 Cybersecurity Learning Standards. A detailed list of standards to consider adding to the CS standards is provided in Appendix E.

1. **Elementary school.**
    a. Hardware/software: Students should know the components or parts of computing devices.
    b. Security: Students should know what a good password is and understand the importance of strong passwords. They should also understand what personal information is and how to protect it.
2. **Middle school.**
    a. Networks: Students should have knowledge about protocols used to transmit data across networks.
    b. Security: Students should be knowledgeable about ways to physically and digitally keep devices and information secure. Digital security knowledge should include methods of cryptography to securely transmit data.
3. **High school.**
    a. Networks: Students should have knowledge about threats and vulnerabilities, including attacks that affect the security of sensitive data.
    b. Security: Students should have knowledge of the roles of software and software developers in keeping devices and information secure. They should also be knowledgeable of different security measures (including encryption), understand the strengths and weaknesses of the measures, and understand potential security threats.
4. **Not grade-specific.**
    a. Consider whether to include the following topics: Cyberbullying, Digital Footprint, Internet of Things, Cloud Computing, and Data Loss.

Data and Analysis

These learning outcomes for the Data and Analysis topic area in the *Reimagining CS Pathways* report are closely related to content from the CCSSM, GAISE II, and NGSS:

DA.1 Identify and define data types (e.g., string, numeric, Boolean)

DA.6 Transform and prepare (e.g., normalize, merge, clean) data

DA.10 Evaluate approaches to cleaning data in a given context

DA.11 Assess whether and how a given question can be answered using computational methods and data, and what specific data is needed

DA.13 Evaluate data visualizations for clarity, potential biases, etc.

DA.14 Select, organize, interpret, and visualize large datasets from multiple sources to support a claim and/or communicate information

DA.15 Devise plans for using data to solve a problem

DA.16 Create a data analysis artifact (e.g., a visualization) using principles of human-centered design

The revised CS standards in Data and Analysis should be aligned with students' learning in math, science, and statistics to ensure students will be successful with these outcomes. The recommendations below follow from aligning relevant standards and practices from the CCSSM, GAISE II, and the NGSS. The detailed alignment is provided in Appendix F. The recommendations also consider the CCSSELA standards.

1. **All grades.**
    a. Explicitly reference statistical problem-solving as a multi-step process in the standards and systematically build students' capacity in all steps. Consider using or adapting the four-step statistical problem-solving process from the GAISE II: (1) formulate statistical investigative questions, (2) collect/consider the data, (3) analyze the data, and (4) interpret the results.
    b. Students should read, write, and speak with other students about data and analysis to build fluency with technical terms and how they are used in the context of data and analysis (e.g., "variable" in a dataset vs. a computer program vs. a mathematical equation) and develop their abilities to comprehend, reference, evaluate, and produce informative/explanatory and argumentative text and oral/multimedia presentations about statistical investigations.

2. **Elementary school.** In elementary school, students are still learning the basics of quantity and measurement, but the CS standards can guide students to leverage their natural curiosity about the world into asking questions of data.
    a. Students should ask and answer questions of small datasets collected in familiar contexts. Questions will generally focus on a single attribute, such as the lengths of objects or the numbers of objects in different categories. Students can collect the data by hand, through counting, categorizing, and measuring objects, or use data that has already been collected. Students should distinguish between quantitative and qualitative data (e.g., words vs. numbers) and know when to use each. Answers can be given in response to structured prompts.
    b. Students should begin using simple computational tools to make basic data tables, picture graphs, bar graphs, and line graphs.

3. **Middle school.** In middle school, students begin learning about foundational concepts in data science in their math classes—variability, distributions, sampling, probability, and other random processes. Towards the end of middle school, students will begin exploring associations between two variables and drawing informal conclusions about them. In science, students will be working with data related to scientific phenomena and data generated in the course of testing their engineering designs. Middle school is an opportune time to show students how computing can support their explorations and understanding of data.

a. Students should ask and answer questions of large datasets (e.g., hundreds or thousands of cases) that cannot be easily summarized manually and that are collected from a variety of contexts, including science, social science, and humanities. Students should be able to pose a question involving one or two variables in the data, describe how the data were collected, use concepts from math and statistics to generate descriptive summary statistics for the variables of interest (e.g., measures of center and variability, calculating percentages), make informal interpretations, and acknowledge the limitations of their investigation. Students should also use these datasets to reinforce their understanding of concepts they are learning in math that are more readily illustrated with larger datasets.

b. Students should use computational tools to collect and store data (e.g., through online surveys or sensors). Students should begin developing understanding of spreadsheets and how computational tools can assist with transforming, summarizing, and representing/visualizing data (especially using tables, bar charts, line graphs, and scatterplots).

4. **High school.** In high school, students begin performing more complex data investigations that incorporate their understanding of statistics, probability, and functions to analyze data, model relationships, and make predictions.

    a. Students should ask and answer complex questions involving large datasets collected from a variety of contexts, including science, social science, and humanities. These questions can involve multiple variables/merging of multiple datasets. Students should develop and execute plans for collecting, cleaning, and analyzing their data using computational tools. Students should visualize their data and apply algebraic thinking to data analysis (e.g., fitting linear and non-linear functions). Students should formally report out their findings, either in written reports or in presentations.

    b. Students should use spreadsheets and other computational tools to transform, analyze, and visualize data and create simulations. Students should develop test cases to ensure computations and simulations perform as intended. Advanced students may begin using statistical software that requires programming to clean data, conduct descriptive and inferential statistical analysis, and create/modify simulations.

Artificial Intelligence

These learning outcomes for Algorithms, Programming, Data and Analysis, and Preparation for the Future topic areas in the *Reimagining CS Pathways* report are closely related to content from the AI4K12 framework:

AL.3 Describe the difference between traditional algorithms and artificial intelligence/machine learning (AI/ML) algorithms and, at a high level, describe how AI/ML algorithms work

PR.5 Use prompt engineering, code generation tools, or other AI technologies to plan, write, test, and debug code

DA.3 Describe, at a high level, the role of data in AI/ML applications

DA.12 Assess societal impacts of data analysis and related ethical issues (e.g., biased data used to train AI systems, attribution related to products of generative AI)

PF.1 Identify pathways and careers that involve computing

PF.7 Assess societal impacts and related ethical issues of emerging and future developments in computing (e.g., the impact of quantum computing on security)

PF.8 Evaluate the use of emerging technologies (e.g., generative AI) for accuracy and to meet specific needs

PF.10 Create a plan to apply an emerging technology to meet a need using principles of human-centered design

We have the following recommendations for the revised CS standards in Artificial Intelligence based on overlaps between the AI4K12 framework and CSTA K–12 CS Standards (Appendix G).

1. **Elementary school.**
    a. Representation: Students should identify examples of representation and explain how information is represented in programs.
    b. Societal Impacts/Ethics: Students should explain how AI is used in daily life, how AI has impacted society, and how to develop AI that is inclusive of diverse groups of users.
2. **Middle school.**
    a. Representation: Students should explain how artifacts (e.g., sound) are digitally represented in a computer.
    b. Societal Impacts/Ethics: Students should explain how people's goals and values can influence the design of AI, how the design process can incorporate those goals and values, and how AI can show biases toward different cultures.
    c. Programming Using Generative AI: Students should use generative AI to aid their programming of novel applications.
3. **High school.**
    a. Representation: Students should explain how information is structured about people, places, or things.
    b. Societal Impacts/Ethics: Students should evaluate the design of AI systems to ensure that those systems include a plan for accountability and a respect for privacy. Students should use an ethical design process to design AI, explain ethical dilemmas that might arise due to AI, and predict how AI can change society.
    c. Machine Learning: Students should define and explain basic concepts of machine learning (e.g., supervised learning), and identify examples of human learning that are similar to machine learning algorithms.
    d. Programming Using Generative AI: Students should use generative AI to program novel applications.

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Appendix A: Comparisons Between CS Practices and Other Practices

CS Practice	Standards for Mathematical Practice	Science and Engineering Practices	Technological and Engineering Practices	Career Ready Practices
1. Fostering an inclusive computing culture			**TEP6:** Collaboration	**CRP12:** Work productively in teams while using cultural/ global competence
2. Collaborating around computing	**SMP5:** Use appropriate tools strategically			**CRP12:** Work productively in teams while using cultural/ global competence
3. Recognizing and defining computational problems	**SMP1:** Make sense of problems and persevere in solving them	**SEP1:** Asking questions (for science) and defining problems (for engineering) **SEP5:** Using mathematics and computational thinking	**TEP3:** Making and doing	**CRP8:** Utilize critical thinking to make sense of problems and persevere in solving them
4. Developing and using abstractions	**SMP2:** Reason abstractly and quantitatively **SMP4:** Model with mathematics **SMP7:** Look for and make use of structure **SMP8:** Look for and express regularity in repeated reasoning	**SEP2:** Developing and using models **SEP3:** Planning and carrying out investigations **SEP5:** Using mathematics and computational thinking **SEP6:** Constructing explanations (for science) and designing solutions (for engineering)		

CS Practice	Standards for Mathematical Practice	Science and Engineering Practices	Technological and Engineering Practices	Career Ready Practices
5. Creating computational artifacts		**SEP3:** Planning and carrying out investigations **SEP5:** Using mathematics and computational thinking **SEP6:** Constructing explanations (for science) and designing solutions (for engineering)	**TEP3:** Making and doing	
6. Testing and refining computational artifacts	**SMP4:** Model with mathematics	**SEP2:** Developing and using models **SEP3:** Planning and carrying out investigations **SEP6:** Constructing explanations (for science) and designing solutions (for engineering)	**TEP3:** Making and doing **TEP5:** Optimism	**CRP7:** Employ valid and reliable research strategies
7. Communicating about computing	**SMP3:** Construct viable arguments and critique the reasoning of others **SMP6:** Attend to precision	**SEP4:** Analyzing and interpreting data **SEP7:** Engaging in argument from evidence **SEP8:** Obtaining, evaluating, and communicating information	**TEP7:** Communication	**CRP4:** Communicate clearly, effectively and with reason

CS Practice	Standards for Mathematical Practice	Science and Engineering Practices	Technological and Engineering Practices	Career Ready Practices
No parallel in CS practices			**TEP1:** Systems thinking **TEP2:** Creativity **TEP4:** Critical thinking **TEP8:** Attention to ethics	**CRP1:** Act as a responsible and contributing citizen and employee **CRP2:** Apply appropriate academic and technical skills **CRP3:** Attend to personal health and financial well-being **CRP5:** Consider the environmental, social and economic impacts of decisions **CRP6:** Demonstrate creativity and innovation **CRP9:** Model integrity, ethical leadership, and effective management **CRP10:** Plan education and career path aligned to personal goals **CRP11:** Use technology to enhance productivity

Appendix B: Randomly Selected Sample Standards and Word Counts

Common Core State Standards for Mathematics

	Standard		Example	
ID	**Text**	**# Words**	**Text**	**# Words**
1.OA.D.8	Determine the unknown whole number in an addition or subtraction equation relating three whole numbers.	15	For example, determine the unknown number that makes the equation true in each of the equations 8 + ? = 11, 5 = _ – 3, 6 + 6 = _.	19
2.MD.A.3	Estimate lengths using units of inches, feet, centimeters, and meters.	10	--	--
4.G.A.3	Recognize a line of symmetry for a two-dimensional figure as a line across the figure such that the figure can be folded along the line into matching parts. Identify line-symmetric figures and draw lines of symmetry.	36	--	--
5.OA.A.2	Write simple expressions that record calculations with numbers, and interpret numerical expressions without evaluating them.	15	For example, express the calculation "add 8 and 7, then multiply by 2" as 2 × (8 + 7). Recognize that 3 × (18932 + 921) is three times as large as 18932 + 921, without having to calculate the indicated sum or product.	34
6.RP.A.1	Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.	18	For example, "The ratio of wings to beaks in the bird house at the zoo was 2:1, because for every 2 wings there was 1 beak." "For every vote candidate A received, candidate C received nearly three votes."	39
8.SP.A.2	Know that straight lines are widely used to model relationships between two quantitative variables. For scatter plots that suggest a linear association, informally fit a straight line, and informally assess the model fit by judging the closeness of the data points to the line.	44	--	--
HSA.REI.A.2	Solve simple rational and radical equations in one variable, and give examples showing how extraneous solutions may arise.	18	--	--

	Standard		Example	
ID	**Text**	**# Words**	**Text**	**# Words**
HSF.LE.A.1.C	Recognize situations in which a quantity grows or decays by a constant percent rate per unit interval relative to another.	20	--	--
HSS.ID.C.7	Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of the data.	21	--	--
HSS.CP.B.8	Apply the Addition Rule, P(A or B) = P(A) + P(B) – P(A and B), and interpret the answer in terms of the model.	14	--	--
Median # Words		18		34

Next Generation Science Standards

	Performance Expectation		Clarification Statement and Assessment Boundary	
ID	**Text**	**# Words**	**Text**	**# Words**
K-PS2-1	Plan and conduct an investigation to compare the effects of different strengths or different directions of pushes and pulls on the motion of an object.	25	Examples of pushes or pulls could include a string attached to an object being pulled, a person pushing an object, a person stopping a rolling ball, and two objects colliding and pushing on each other.	35
			Assessment is limited to different relative strengths or different directions, but not both at the same time. Assessment does not include non-contact pushes or pulls such as those produced by magnets.	31
K-ESS3-3	Communicate solutions that will reduce the impact of humans on the land, water, air, and/or other living things in the local environment.	23	Examples of human impact on the land could include cutting trees to produce paper and using resources to produce bottles. Examples of solutions could include reusing paper and recycling cans and bottles.	32
2-PS1-2	Analyze data obtained from testing materials to determine which materials have the properties that are best suited for an intended purpose.	21	Examples of properties could include, strength, flexibility, hardness, texture, and absorbency.	11
			Assessment of quantitative measurements is limited to length.	8

	Performance Expectation		Clarification Statement and Assessment Boundary	
ID	**Text**	**# Words**	**Text**	**# Words**
4-PS4-2	Develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen.	19	Assessment does not include knowledge of specific colors reflected and seen, the cellular mechanisms of vision, or how the retina works.	21
MS-PS3-2	Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.	26	Emphasis is on relative amounts of potential energy, not on calculations of potential energy. Examples of objects within systems interacting at varying distances could include: the Earth and either a roller coaster cart at varying positions on a hill or objects at varying heights on shelves, changing the direction/orientation of a magnet, and a balloon with static electrical charge being brought closer to a classmate's hair. Examples of models could include representations, diagrams, pictures, and written descriptions of systems.	80
			Assessment is limited to two objects and electric, magnetic, and gravitational interactions.	12
MS-LS4-3	Analyze displays of pictorial data to compare patterns of similarities in the embryological development across multiple species to identify relationships not evidence in the fully formed anatomy.	27	Emphasis is on inferring general patterns of relatedness among embryos of different organisms by comparing the macroscopic appearance of diagrams or pictures.	22
			Assessment of comparisons is limited to gross appearance of anatomical structures in embryological development.	14
MS-LS4-4	Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment.	28	Emphasis is on using simple probability statements and proportional reasoning to construct explanations.	13
HS-LS2-7	Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.	18	Examples of human activities can include urbanization, building dams, and dissemination of invasive species.	14
HS-LS3-1	Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.	24	Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.	18

	Performance Expectation		Clarification Statement and Assessment Boundary	
ID	**Text**	**# Words**	**Text**	**# Words**
HS-LS3-2	Make and defend a claim based on evidence that inheritable genetic variations may result from (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.	35	Emphasis is on using data to support arguments for the way variation occurs.	13
			Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.	18
HS-ESS1-6	Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.	24	Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.	70
Median # Words		24		18

Appendix C: Aligned Impacts and Ethics Learning Progressions for STEL and NCSS Standards

Grade[8]	Summary of related STEL benchmarks	Summary of related NCSS learning expectations
PreK K 1 2	**Standard 4: Impacts of Technology** *STEL-4B.* Illustrate helpful and harmful effects of technology *STEL-4C.* Compare simple technologies to evaluate their impacts **Standard 5: Influence of society on technological development** *STEL-5B.* Explore how technologies are developed to meet individual and societal needs and wants *STEL-5C.* Investigate the use of technologies in the home and community	What are examples of science and technology that have impacted individuals and society? What can be learned from the past about how new technologies resulted in societal change? *Learners will understand:* • That science and technology can have both positive and negative impacts on individuals, society, and the globe *Learners will be able to:* • Identify examples of the use of science and technology in society as well as consequences of their use • Research a scientific topic or type of technology developed in a particular time or place and determine its impact on people's lives • Identify the points of view expressed in information sources regarding science and technology *Learners demonstrate understanding by:* • Researching, designing, and presenting a project including illustrations or a model showing the positive and negative aspects of the uses of technology in the school or local community
3 4	**Standard 4: Impacts of Technology** *STEL-4F.* Describe the helpful and harmful effects of technology *STEL-4J.* Predict how certain aspects of their daily lives would be different without given technologies **Standard 5: Influence of society on technological development** *STEL-5E.* Explain how technologies are developed or adapted when individual or societal needs and wants change	

[8] STEL contains two elementary grade bands: preK–2 and 3–5 and a middle school grade band: 6–8. NCSS defines "early grades" as preK–4 and middle grades as 5–8.

Grade[8]	Summary of related STEL benchmarks	Summary of related NCSS learning expectations
5		What are current and historic examples of science and technology that have impacted individuals, society, and the world? What can be learned from the past about how new technologies resulted in both planned and unanticipated changes? How do we evaluate whether developments in science and technology are harmful or beneficial to a society? *Learners will understand:* • Science and technology have had both positive and negative impacts upon individuals, societies, and the environment in the past and present • Science and technology have changed people's perceptions of the social and natural world, as well as their relationship to the land, economy and trade, their concept of security, and their major daily activities • Values, beliefs, and attitudes that have been influenced by new scientific and technological knowledge • The need for laws and policies to govern scientific and technological applications • That there are gaps in access to science and technology around the world *Learners will be able to:* • Ask and find answers to questions about the ways in which science and technology affect people's lives today in different places, and have done so in the past • Seek and evaluate varied perspectives when weighing how specific applications of science and technology have impacted individuals and society • Review sources to identify the purposes, points of view, biases, and intended audiences of reports and discussions of science and technology • Select, organize, evaluate, and communicate information about the impact of science or technology on a society today or in the past *Learners demonstrate understanding by:* • Discussing current and past issues involving science and technology, and their consequences for society
6 7 8	**Standard 4: Impacts of Technology** *STEL-4K.* Examine the ways that technology can have both positive and negative effects at the same time. *STEL-4N.* Analyze examples of technologies that have changed the way people think, interact, and communicate. *STEL-4O.* Hypothesize what alternative outcomes (individual, cultural, and/or environmental) might have resulted had a different technological solution been selected. **Standard 5: Influence of society on technological development** *STEL-5G.* Evaluate trade-offs based on various perspectives as part of a decision process that recognizes the need for careful compromises among competing factors.	

9–12	**Standard 4: Impacts of Technology** *STEL-4P.* Evaluate ways that technology can impact individuals, society, and the environment *STEL-4T.* Evaluate how technologies alter human health and capabilities **Standard 5: Influence of society on technological development** *STEL-5H.* Evaluate a technological innovation that arose from a specific society's unique need or want. *STEL-5I.* Evaluate a technological innovation that was met with societal resistance, impacting its development *STEL-5J.* Design an appropriate technology for use in a different culture.	How have changes in science and technology impacted groups, societies, nations, and the environment, past and present, in both positive and negative ways? What can be learned from the past about how science and technology have resulted in broad social change, planned or unanticipated? What criteria can we use to determine whether developments in science and technology are harmful or beneficial to a society? How do we balance the possibilities and advancements in science and technology against ways in which they may conflict with existing beliefs, ethics, and values? *Learners will understand:* • Consequences of science and technology for individuals and societies • Decisions regarding the uses and consequences of science and technology are often complex because of the need to choose between or reconcile different viewpoints • Findings in science and advances in technology sometimes create ethical issues that test our standards and values • Science, technology, and their consequences are unevenly available across the globe • That achievements in science and technology are increasing at a rapid pace and can have both planned and unanticipated consequences *Learners will be able to:* • Ask and find answers to questions about the impact of science and technology in the past and present, and in different places and societies • Seek and evaluate varied perspectives when weighing how specific applications of science and technology have impacted individuals and societies in an interdependent world • Identify and select appropriate information from multiple sources with varied perspectives for research into issues related to science and technology • Identify the purposes, points of view, biases, and intended audience of reports and discussions related to issues involving science and technology • Select, organize, analyze, and evaluate information, and communicate findings regarding the impact of science or technology on a society today or in the past • Identify and analyze reactions to science and technology from the past or present, and predict ongoing effects in economic, geographical social, political, and cultural areas of life

Grade[8]	Summary of related STEL benchmarks	Summary of related NCSS learning expectations
		Learners demonstrate understanding by: • Creating and explaining two political cartoons that take opposing stands on a controversial scientific or technological issue or advance • Creating a short documentary on a current or past scientific or technological issue that highlights societal consequences and the varied positions of those impacted

Appendix D: Aligned Computing Systems and Security Learning Progressions for CSTA K–12 CS Standards and K–12 Cybersecurity Learning Standards

The learning progressions on the following pages are the most closely related topics for Computing Systems and Security.

Grade	Summary of Related CSTA K–12 CS Standards	Summary of Related K–12 Cybersecurity Learning Standards
K–2	1A-NI-04 Explain what passwords are and why we use them, and use strong passwords to protect devices and information from unauthorized access.	K–2.SEC.AUTH Describe the concept of a good password and its importance.
	1A-CS-02 Use appropriate terminology in identifying and describing the function of common physical components of computing systems (hardware)	K–2.CS.HARD Identify the components or parts of computing devices.
3–5	1B-NI-05 Discuss real-world cybersecurity problems and how personal information can be protected.	3–5.DC.PPI Define personally identifiable information (PII). [6–8].DC.PPI.2 Examine techniques to detect, correct, and prevent disclosure of PII. [9–12].DC.PPI.1 Explain the importance of social identity and the implications of online activity regarding private data, long-term career impacts, and the permanence of digital data.
6–8	2-NI-05 Explain how physical and digital security measures protect electronic information.	6–8.SEC.ACC Explain the concept of access control and how to limit access to authorized users. [K–2].SEC.CIA Identify the concepts of Confidentiality, Integrity, and Availability as presented in the CIA Triad. [3–5].SEC.CIA Describe the concepts of the CIA Triad and how they work to protect information. [3–5].SEC.ACC Describe the concept of appropriate access to private information. [9–12].SEC.DATA Formulate a plan to apply security measures to protect data in all three states. [9–12].SEC.INFO Distinguish the different types of attacks that affect information security for individuals and organizations.

Grade	Summary of Related CSTA K–12 CS Standards	Summary of Related K–12 Cybersecurity Learning Standards
	2-NI-06 Apply multiple methods of encryption to model the secure transmission of information.	6–8.SEC.CRYP Discuss methods and the need for encrypting information when it is being exchanged, e.g., http vs. https.
	2-NI-04 Model the role of protocols in transmitting data across networks and the Internet.	6–8.CS.PROT Identify the protocol connection types used for different services available online. [9–12].CS.PROT.1 Compare and contrast the ports and protocols used for different services available online.
9–10	3A-NI-08 Explain tradeoffs when selecting and implementing cybersecurity recommendations.	9–12.SEC.COMP Evaluate Defense in Depth strategies that can protect simple networks. 9–12.SEC.CTRL Justify the use of Defense in Depth and the need for physical access controls. 9–12.SEC.AUTH Evaluate authentication and authorization methods and the risks associated with failure. 9–12.SEC.DATA Formulate a plan to apply security measures to protect data in all three states.
	3A-NI-05 Give examples to illustrate how sensitive data can be affected by malware and other attacks	9–12.SEC.INFO Distinguish the different types of attacks that affect information security for individuals and organizations. [6–8].SEC.INFO Analyze threats and vulnerabilities to information security for individuals and organizations.
11–12	3B-NI-04 Compare ways software developers protect devices and information from unauthorized access.	[6–8].CS.APPS Discuss the role that software plays in the protection of a secure system.

Appendix E: Computing Systems and Security Learning Progressions in K–12 Cybersecurity Learning Standards to Consider Adding to the New CSTA K–12 CS Standards

	K–2	3–5	6–8	9–12
Cyberbullying	K–2.DC.CYBL Discuss examples of cyberbullying and model age-appropriate responses to cyberbullying.	3–5.DC.CYBL Discuss and demonstrate examples of cyberbullying and methods of age-appropriate intervention.	6–8.DC.CYBL Develop strategies to raise awareness of the effects of, and methods to identify and prevent, cyberbullying.	9–12.DC.CYBL Prepare a plan to raise awareness of the effects of cyberbullying.
Digital Footprint	K–2.DC.FOOT Differentiate between good and bad online behavior.	3–5.DC.FOOT Describe the concept of a digital footprint.	6–8.DC.FOOT.1 Recognize the many sources of data that make up a digital footprint. 6–8.DC.FOOT.2 Recognize the permanence of a digital footprint.	9–12.DC.FOOT Examine the implications of both positive and negative digital footprints.
Internet of Things	K–2.CS.IOT Identify examples of devices that are part of the Internet of Things.	3–5.CS.IOT Define the Internet of Things.	6–8.CS.IOT Evaluate the risks and benefits of Internet of Things devices.	9–12.CS.IOT Analyze the vulnerabilities of Internet of Things devices.
Cloud Computing	K–2.CS.CC State the benefits of storing and sharing information using cloud computing.	3–5.CS.CC.1 Demonstrate ways to store and share information using cloud computing. 3–5.CS.CC.2 Demonstrate safe cloud computing practices.	6–8.CS.CC Identify the advantages and disadvantages of various cloud computing models.	9–12.CS.CC Evaluate the risks and benefits of cloud computing.
Data Loss	K–2.CS.LOSS Define data loss and service outages.	3–5.CS.LOSS Explain the role and importance of backups (e.g., via auto-save features).	6–8.CS.LOSS Explain the role and importance of backups (e.g., via redundant systems).	9–12.CS.LOSS Develop a plan for risk mitigation that implements redundancy.

Appendix F: Aligned Data and Analysis Learning Progressions for CCSSM, GAISE II, and NGSS Practices

These learning progressions focus on the Measurement and Data and Statistics and Probability domains in the CCSSM and SEP4: *Analyzing and interpreting data* and SEP5: *Using mathematics and computational thinking* from the NGSS. These concepts and practices are the most closely related concepts and practices for Data and Analysis. Content from the CCSSM, GAISE II, and NGSS is paraphrased and not intended to be a comprehensive catalog of standards, practices, and instructional recommendations from each source.

Summary of Related CCSSM Standards		Summary of Related GAISE II Instructional Recommendations	Summary of NGSS SEPs 4 and 5
K	Count and describe, compare, and categorize objects based on their attributes.	*All recommendations that align to elementary school CCSSM are Level A* **I. Formulate Statistical Investigative Questions** Understand and experience different types of statistical investigative questions. Pose statistical investigative questions involving familiar contexts and small datasets. **IV: Interpret Results** Use evidence to answer statistical investigative questions and communicate results with teacher guidance.	**SEP 4: Analyzing and interpreting data** Record and share observations. Use observations to describe patterns and relationships to answer questions. **SEP 5: Using mathematics and computational thinking** Decide when to use qualitative vs. quantitative data. Use counting and numbers to identify and describe patterns. Describe, measure, and compare quantitative attributes of objects. Display data using simple graphs.
1	Measure and compare/order objects using arbitrary length units (e.g., a paper clip). Organize and represent data with up to three categories, answering data questions about the number of data points and comparing the number of data points in each category.		
2	Measure and estimate lengths using standard whole units. Create line plots to represent measurement data. Create picture graphs and bar graphs to represent data with up to four categories and answer data questions using information in the graphs (e.g., comparing the quantities in two categories).		

Summary of Related CCSSM Standards	Summary of Related GAISE II Instructional Recommendations	Summary of NGSS SEPs 4 and 5
3 Measure and estimate lengths using half and quarter units. Create line plots to represent measurement data. Create scaled picture graphs and bar graphs to represent data with several categories, and answer "how many more/less" questions using the graphs. 4 Create line plots to represent measurement data using fractional units (½, ¼, ⅛). Solve addition and subtraction problems using information in the line plots. 5 Create line plots to represent measurement data using fractional units (½, ¼, ⅛). Solve problems requiring fraction operations using information in the line plots.	*All recommendations that align to elementary school CCSSM are Level A* **I. Formulate Statistical Investigative Questions** Understand and experience different types of statistical investigative questions. Pose statistical investigative questions involving familiar contexts and small datasets. **IV: Interpret Results** Use evidence to answer statistical investigative questions and communicate results with teacher guidance.	**SEP 4: Analyzing and interpreting data** Represent data in tables and graphical displays to reveal patterns and relationships. When possible and feasible, use digital tools to analyze and interpret data. **SEP 5: Using mathematics and computational thinking** Decide whether to use quantitative or qualitative data. Organize simple datasets to reveal patterns. Describe, measure, and/or graph quantities related to scientific questions and engineering problems.

6	Recognize statistical questions, which are questions that anticipate variability in the data and account for it in the answers[9]. Summarize datasets by reporting the numbers of observations, describing the attributes in the data and how they were measured, and calculating quantitative measures of center and variability.	**I. Formulate Statistical Investigative Questions** *Level B* Understand that there are different types of statistical investigative questions and they can be used to articulate research topics. Pose statistical investigative questions involving large datasets, including questions about a population, changes over time, and data collected from devices. **II. Collect Data/Consider Data** *Level A* Understand the basic properties of datasets and the variables within them and how data can be collected. Interrogate datasets to understand the variables and how they relate to statistical investigative questions. *Level B* Understand that data are collected with a purpose and can be organized and stored in a variety of structures (e.g., spreadsheets). Recognize the limitations of datasets and data collection methods. Interrogate datasets to determine how the data were collected and understand the variables in the data. Understand how sampling and random assignment are used to answer statistical investigative questions. **III. Analyze the Data** *Level A* Understand and represent data distributions for categorical and quantitative variables. Describe key features of data distributions for quantitative variables, such as measures of center, variability, and shape. Compare distributions and identify associations between variables. *Level B* Visualize data distributions for quantitative variables. Use measures of center, variability, and shape to reason about two distributions and compare them. Explore patterns of association between two variables. **IV: Interpret Results** *Level B*	**SEP 4: Analyzing and interpreting data** Construct and use graphical displays of large datasets to identify relationships between variables. Use concepts from statistics and probability, including measures of center and variability, to analyze and characterize data. Consider the limitations of datasets and data analysis. Distinguish between causal and correlational relationships. **SEP 5: Using mathematics and computational thinking** Use digital tools (e.g., computers) to analyze very large datasets for patterns and trends. Use mathematical representations and apply mathematical concepts and/or processes (e.g., ratio, rate, percent[10]) to scientific questions and engineering problems.
7	Understand that statistics can be used to learn about a population by examining a sample of the population and generalizing from the sample if the sample is representative. Draw multiple random samples from a dataset to gauge the variability in estimates and predictions from each sample. Use the data from a random sample to draw an inference about a population. Make informal comparative inferences about two populations, such as by assessing the degree of visual overlap between two data distributions and comparing measures of center and variability.		
8	Create scatterplots to investigate associations between two variables, and describe the relationships. When scatterplots suggest a linear relationship, model the relationship by informally fitting a straight line to the points and assess the model fit by judging the closeness of the data points to the line.		

[9] The example provided in the CCSSM ("How old am I?") is not a statistical question because there is a single numerical answer. "How old are the students in my school?" is a statistical question because the answer must contend with the variability in students' ages.
[10] Ratios, rates, and percents are introduced in sixth grade in the CCSSM.

Summary of Related CCSSM Standards	Summary of Related GAISE II Instructional Recommendations	Summary of NGSS SEPs 4 and 5
	Use statistical evidence to answer statistical investigative questions and communicate results comprehensively, with some teacher guidance. State the limitations of the sample and recognize the uncertainty in generalizing beyond the sample. Compare results for different conditions in an experiment	

Summary of Related CCSSM Standards	Summary of Related GAISE II Instructional Recommendations	Summary of NGSS SEPs 4 and 5
HS Represent data with plots on the real number line (dot plots, histograms, and box plots). Create scatterplots with two quantitative variables and describe their relationship. Graph linear and exponential functions. Distinguish between situations that can be modeled using linear and exponential functions. Understand statistics as a process for making inferences about population parameters based on a random sample from that population. Recognize the different purposes of sample surveys, experiments, and observational studies. Use data from sample surveys or randomized experiments to draw inferences. Evaluate reports based on data.	*All recommendations that align to high school CCSSM are Level C* **I. Formulate Statistical Investigative Questions** Pose complex statistical investigative questions, such as those involving multiple variables or requiring causal inference. Determine how data can be collected and analyzed to answer the questions. **II. Collect Data/Consider Data** Distinguish among different types of statistical investigations, such as surveys, observational studies, and experiments. Understand good practices for sampling, data collection, and data handling. Apply practices when collecting primary data or selecting data for secondary analysis. Understand complex considerations around research design, such as the role of random sampling in surveys, random assignment in experiments, issues around bias and confounding variables, and the generality of findings. **III. Analyze the Data** Use technology to subset, filter, and transform data. Summarize and describe relationships among multiple variables by visualizing the data and calculating summary statistics and confidence intervals. Use simulations to understand and approximate sampling distributions and to investigate associations between categorical variables. **IV: Interpret Results** Use statistical evidence to answer statistical investigative questions and communicate results through formal reports and presentations. Understand how missing data and outliers may influence an analysis. Understand how to interpret margins of error and *p*-values.	**SEP 4: Analyzing and interpreting data** Analyze data using tools, technologies, or models. Analyze data using concepts from statistical probability, such as calculating correlation coefficients and best-fit lines. Consider the limitations of datasets and data analysis. Distinguish between causal and correlational relationships. **SEP 5: Using mathematics and computational thinking** Use algebraic thinking in analysis (e.g., fitting linear and non-linear functions). Create and/or revise computational models or simulations of a phenomenon, device, process, or system. Test mathematical expressions, computer programs, algorithms, or simulations to see if they “make sense” by comparing their outcomes to the real world.

Appendix G: Aligned Artificial Intelligence Learning Progressions for CSTA K–12 CS Standards and AI4K12 Framework

The learning progressions on the following pages are the most closely related topics for Artificial Intelligence.

Grade	Summary of Related CSTA K–12 CS Standards	Summary of Related AI4K12 Guidelines
K–2	1A-AP-09 Model the way programs store and manipulate data by using numbers or other symbols to represent information.	2-A-i LO: Construct a map of a home, school, or neighborhood. EU: The map is not the territory. A map is a *representation* of a territory. 2-A-ii LO: Give examples of symbols you encounter in daily life. EU: Concepts can be represented using symbols in place of words. 2-A-iv LO: Identify the features that make each object in a collection unique and create a table of features to organize the objects. EU: Objects can be described in terms of the features they possess.
	1A-IC-16 Compare how people live and work before and after the implementation or adoption of new computing technology.	5-B-i LO: Identify devices in daily life that use AI technologies. EU: AI technologies are part of any device that includes speech recognition or computer vision, such as smartphones, intelligent home assistants, and modern automobiles. 5-C-i LO: Identify current uses of AI and how they have impacted society. EU: Society has undergone changes because of AI and this will continue in the future.
3–5	1B-IC-18 Discuss computing technologies that have changed the world, and express how those technologies influence, and are influenced by, cultural practices.	5-A-iii LO: Create a model card for a classification or prediction model. EU: Model cards support transparency by explaining the intended use, training dataset, accuracy, and limitations of the model. 5-B-i LO: Describe how AI-powered services are used in daily life. EU: AI-powered services are used to look up information, to provide voice interfaces to many kinds of apps, to make recommendations based on a person's interests, and to make cars safer. 5-C-i LO: Identify changes in how sectors of society operate due to the introduction of AI. EU: Every sector of society is changing (or will change) as a result of the introduction of AI.

Grade	Summary of Related CSTA K–12 CS Standards	Summary of Related AI4K12 Guidelines
	1B-IC-19 Brainstorm ways to improve the accessibility and usability of technology products for the diverse needs and wants of users.	1-C-ii LO: Discuss how domain knowledge needs to be broad enough to encompass all the groups an application is intended to serve. EU: Speech recognition systems need to accommodate different types of accents and alternative pronunciations. Music recognition systems must know about different musical genres.
	1B-IC-20 Seek diverse perspectives for the purpose of improving computational artifacts.	1-C-ii LO: Discuss how domain knowledge needs to be broad enough to encompass all the groups an application is intended to serve. EU: Speech recognition systems need to accommodate different types of accents and alternative pronunciations. Music recognition systems must know about different musical genres.
6–8	2-DA-07 Represent data using multiple encoding schemes.	1-A-iii [3–5] LO: Explain how images are represented digitally in a computer. EU: Images are encoded as 2D arrays of pixels, where each pixel is a number indicating the brightness of that piece of the image, or an RGB value indicating the brightness of the red, green, and blue components of that piece.
	2-IC-21 Discuss issues of bias and accessibility in the design of existing technologies.	5-A-i LO: Evaluate the ways various stakeholders' goals and values influence the design of AI systems. EU: The behavior of AI systems is determined by the choices of the designers, which may involve tradeoffs between conflicting goals and values. If other stakeholders' perspectives aren't given sufficient weight, there could be negative consequences for users. 5-A-iii LO: Evaluate ways that AI system designers can learn about and incorporate the values of their stakeholders into the design process. EU: AI systems need to align with the norms and values of the groups they aim to serve. Developers of AI systems need to understand that values vary across cultures and ensure these values inform the design of products they create. 1-C-ii LO: Describe how a vision system might exhibit cultural bias if it lacked knowledge of objects not found in the culture of the people who created it. EU: Domain knowledge must take multiple cultures into account if an AI application is to serve diverse groups.

Grade	Summary of Related CSTA K–12 CS Standards	Summary of Related AI4K12 Guidelines
9–10	3A-DA-10 Evaluate the tradeoffs in how data elements are organized and where data is stored.	2-A-iii LO: Describe how schemas are used to structure information about people, places, or things in knowledge graphs. EU: A schema specifies the attributes of the concept being described, and its relationships to other concepts, e.g., the *Restaurant* schema inherits properties from the *FoodEstablishment* schema.
	3A-IC-29 Explain the privacy concerns related to the collection and generation of data through automated processes that may not be evident to users.	5-A-ii [6–8] LO: Evaluate how an AI system meets the design criteria of accountability and respect for privacy. EU: Accountability in AI systems means designers and decision makers take responsibility for the system's actions. Respect for privacy means the system does not act in ways that violate people's privacy rights. 5-B-ii [6–8] LO: Critique uses of AI technology that can be used to surveil people or violate their privacy. EU: AI technologies endanger privacy by reducing the cost of implementing widespread surveillance and enabling new types of surveillance.
	3A-IC-24 Evaluate the ways computing impacts personal, ethical, social, economic, and cultural practices.	5-A-iii LO: Design an AI system using an ethical design process. EU: Ethical design, at all stages of the design process, considers the values of all stakeholders and upholds the principles of fairness, transparency, explainability, accountability, respect for privacy, and adherence to societal values. 5-B-i LO: Explain the kinds of debates that might arise as AI technology continues to evolve and is further woven into our culture. EU: Some new AI technologies will pose challenges for cultural norms and expectations that society must identify and wrestle with. 5-C-i LO: Predict how a sector of society is likely to change in the short and intermediate term as a result of AI technology. EU: Anticipating and planning for the changes new technology brings is important for the healthy advancement of society.

Grade	Summary of Related CSTA K–12 CS Standards	Summary of Related AI4K12 Guidelines
11–12	3B-AP-08 Describe how artificial intelligence drives many software and physical systems.	3-A-i LO: Define supervised, unsupervised, and reinforcement learning algorithms, and give examples of human learning that are similar to each algorithm. EU: Both supervised and unsupervised learning algorithms find patterns in data. Supervised learning uses features to predict the class label supplied by a teacher; unsupervised learning groups similar instances together, creating its own classes. Reinforcement learning uses trial and error to find a policy for choosing actions that maximizes the reinforcement signal.
	3B-IC-27 Predict how computational innovations that have revolutionized aspects of our culture might evolve.	5-A-iii LO: Design an AI system using an ethical design process. EU: Ethical design, at all stages of the design process, considers the values of all stakeholders and upholds the principles of fairness, transparency, explainability, accountability, respect for privacy, and adherence to societal values. 5-B-i LO: Explain the kinds of debates that might arise as AI technology continues to evolve and is further woven into our culture. EU: Some new AI technologies will pose challenges for cultural norms and expectations that society must identify and wrestle with. 5-C-i LO: Predict how a sector of society is likely to change in the short and intermediate term as a result of AI technology. EU: Anticipating and planning for the changes new technology brings is important for the healthy advancement of society.
	3B-IC-25 Evaluate computational artifacts to maximize their beneficial effects and minimize harmful effects on society.	5-A-iii LO: Design an AI system using an ethical design process. EU: Ethical design, at all stages of the design process, considers the values of all stakeholders and upholds the principles of fairness, transparency, explainability, accountability, respect for privacy, and adherence to societal values. 5-B-i LO: Explain the kinds of debates that might arise as AI technology continues to evolve and is further woven into our culture. EU: Some new AI technologies will pose challenges for cultural norms and expectations that society must identify and wrestle with. 5-C-i LO: Predict how a sector of society is likely to change in the short and intermediate term as a result of AI technology. EU: Anticipating and planning for the changes new technology brings is important for the healthy advancement of society.