CSTA K–12 Computer Science Standards

Revised 2011

The CSTA Standards Task Force

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Executive Summary

Over the past few decades, computers have transformed both the world and the workforce in many profound ways. As a result, computer science and the technologies it enables now lie at the heart of our economy and the way we live our lives. To be well-educated citizens in a computing-intensive world and to be prepared for careers in the 21st century, our students must have a clear understanding of the principles and practices of computer science. No other subject will open as many doors in the 21st century as computer science, regardless of a student's ultimate field of study or occupation.

As the report *Running on Empty: The Failure to Teach Computer Science in the Digital Age* (http://csta.acm.org/Communications/sub/Documents.html) makes clear, the current state of computer science education is unacceptable at a time when computing is driving job growth and new scientific discovery. Roughly two-thirds of the fifty states do not have computer science standards for secondary school education. Even when they exist, computer science standards at the K–8 level often confuse computer science and the use of applications. Despite its importance as an academic field, few states count computer science as a core academic subject for graduation. Rules for computer science teacher certification vary widely from state to state and are often entirely unrelated to the needs of teaching in this discipline. These are national failings and ones that we cannot afford in this digital age.

This document provides comprehensive standards for K–12 computer science education designed to strengthen computer science fluency and competency throughout primary and secondary schools. It is written in response to the pressing need to provide academic coherence between coursework and the rapid growth of computing and technology in the modern world, alongside the need for an educated public that can utilize and build that technology most effectively for the benefit of society.

These standards provide a three-level framework for computer science. The first two levels are aimed at grades K–6 and 6–9 respectively. We expect that the learning outcomes in Level 1 will be addressed in the context of other academic subjects. The learning outcomes in Level 2 may be addressed either through other subjects or in discrete computer science courses. Level 3 is divided into three separate courses: *Computer Science in the Modern World, Computer Science Principles, and Topics in Computer Science*. The standards provided in *Computer Science in the Modern World* reflect learning content that should be mastered by all students; *Computer Science Principles* and *Topics in Computer Science* are courses intended for students with special interest in computer science and other computing careers, whether they are college-bound or not.

These recommendations are not made in a vacuum. We understand the serious constraints under which school districts are operating and the uphill battle that computer science faces in the light of other educational priorities. Thus, we conclude this report with a series of recommendations that are intended to provide support for a long-term evolution of computer science in K–12 schools. Significant progress has been made since the *ACM Model Curriculum for K–12 Computer Science Education* was first published in 2003 and revised in 2006. Many follow-up efforts are still needed, however, to sustain the momentum these standards generate. Teacher training, curriculum innovation, teaching resources, and dissemination are but a few of these challenges.

These learning standards will serve as a catalyst for widespread adoption of computer science education for all K–12 students. We encourage you to read this document and then to take part in the effort to implement these standards in a way that benefits both you and the K–12 education community. Find information about ongoing activities to support computer science education in K–12 at the Computer Science Teachers Association's Web site (csta.acm.org).

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National Standards for K–12 Computer Science

1. Introduction

There is an urgent need to improve the level of public understanding of computer science as an academic and professional field, including its distinctions from management information systems (MIS), information technology (IT), mathematics, and the other sciences. To function in society, every citizen in the 21st century must understand at least the principles of computer science. A broad commitment to, and rigorous implementation of, K–12 computer science courses will create such broad public understanding and also will help to meet the growing needs of the international workforce. Elementary and secondary schools have a unique opportunity and responsibility to address this need.

Computer science is an established discipline at the collegiate and post-graduate levels. It is best defined as "the study of computers and algorithmic processes, including their principles, their hardware and software designs, their applications, and their impact on society." Unfortunately, computer science concepts and courses in the K–12 curriculum have not kept pace with other academic disciplines in the United States. As a result, the general public is not as well educated about computer science as it should be, to the point that the nation faces a serious shortage of computer scientists at all levels that is likely to continue into the foreseeable future.

These computer science standards aim to help address these problems. They provide a framework within which state departments of education and school districts can revise their curricula to better educate young people in this important subject area and thus better prepare students for effective citizenship in the 21st century.

The purpose of this document is to set forth the computer science knowledge and skills that students must have—at all stages of their learning—to enable them to thrive in this new global information economy. It defines a set of learning standards for K–12 computer science and suggests steps needed to enable their implementation. By implementing these standards, schools can introduce the principles and methodologies of computer science to all students, whether they are college or workplace bound. The standards outlined in this document complement existing K–12 computer science and IT curricula where they are already established, especially the Advanced Placement (AP) computer science curricula (AP, 2010) and professional IT certifications.

This document delineates a core set of learning standards designed to provide the foundation for a complete computer science curriculum and its implementation at the K–12 level. To this end, these standards:

1. introduce the fundamental concepts of computer science to all students, beginning at the elementary school level;
2. present computer science at the secondary school level in a way that can fulfill a computer science, math, or science graduation credit;
3. encourage schools to offer additional secondary-level computer science courses that will allow interested students to study facets of computer science in more depth and prepare them for entry into the work force or college; and
4. increase the availability of rigorous computer science for all students, especially those who are members of underrepresented groups.

Our goal is for these standards to be coherent and comprehensible to teachers, administrators, and policy makers. For this reason, our discussions in the early part of this document focus on the current proliferation and confusion of terms that often make this discipline seem ill defined and incomprehensible to those outside the field. We also attempt to describe the importance of computer science education as part

of the intellectual development of students at all levels emphasizing the linkages between computer science and innovation across all disciplines.

All drafts of this report have been informed by feedback from many organizations and individuals. We hope that this final draft will receive widespread dissemination and continued scrutiny from everyone who has interests or experience in K–12 education. To that end, we have published these standards on the CSTA Web site (http://csta.acm.org) as well as in hardcopy form.

These standards are critical to ensuring that students achieve the necessary level of knowledge, skills, and experience to thrive in the modern world. While we recognize that there are many obstacles to adopting rigorous computer science in the K–12 classroom, we cannot as a nation afford to let the current situation continue. If we fail to establish such standards or are unable to implement them effectively, our students will find themselves unprepared to work in the technologically sophisticated world in which they must compete.

2. Computer Science as a Core Discipline

Our lives depend upon computer systems and the people who maintain them to keep us safe on the road and in air, help physicians diagnose and treat health care problems, and play a critical role in the development of many scientific advances. A fundamental understanding of computer science enables students to be both educated consumers of technology and innovative creators capable of designing computing systems to improve the quality of life for all people.

Children of all ages love computing. When given the opportunity, young students enjoy the sense of mastery and magic that programming provides. Older students are drawn to the combination of art, narrative, design, programming, and sheer enjoyment that comes from creating their own virtual worlds. Blending computer science with other interests also provides rich opportunities for learning. Students with an interest in music, for example, can learn about digital music and audio. This field integrates electronics, several kinds of math, music theory, computer programming, and a keen ear for what sounds beautiful, harmonious, or just plain interesting.

Computer science has also made possible profound leaps of innovation and imagination as it facilitates our efforts to solve pressing problems (for example, the prevention or cure of diseases, the elimination of world hunger). It expands our understanding of ourselves as biological systems and of our relationship to the world around us. These advances, in turn, drive the need for educated individuals who can bring the power of computing to help solve complex problems.

It is no longer sufficient to wait until students are in college to introduce these concepts. All of today's students will go on to live a life heavily influenced by computing, and many will work in fields that directly involve computing. They must begin to work with algorithmic problem solving and computational methods and tools in K–12.

2.1 Computer Science is Intellectually Important

The invention of the computer in the 20th century was a "once in a millennium" event, comparable in importance to the development of writing or the printing press. Computers are fundamentally different from other technological inventions in that they directly augment human thought, rather than, say, the functions of our muscles or our senses. Computers have enormous impact on the way we live, think, and act. It is hard to overestimate their importance in the future. In fact, many believe that the true computer revolution will not happen until everyone can understand the technology well enough to use it in truly innovative ways.

So why is it important to study computer science? We live in a digitized, computerized, programmable world, and to make sense of it, we need computer sci-

ence. An engineer using a computer to design a bridge must understand how the maximum capacity estimates were computed and how reliable they are. An educated citizen using a voting machine or bidding in an online auction should have a basic understanding of the underlying algorithms of such conveniences, as well as the security and privacy issues that arise when information is transmitted and stored digitally.

Computer science students learn logical reasoning, algorithmic thinking, design and structured problem solving—all concepts and skills that are valuable well beyond the computer science classroom. Students gain awareness of the resources required to implement, test, and deploy a solution and how to deal with real-world constraints. These skills are applicable in many contexts, from science and engineering to the humanities and business, and they have enabled deeper understanding in these and other areas. Computer simulations are essential to the discovery and understanding of the fundamental rules that govern a wide variety of systems from how ants gather food to how stock markets behave. Computer science is also one of the leading disciplines helping us understand how the human mind works, one of the great intellectual challenges of all time. Thus, much computer-enabled innovation lies ahead of us and computer science is an essential tool for achieving our vast potential.

2.2 Computer Science Leads to Multiple Career Paths

The vast majority of careers in the 21st century will require an understanding of computer science. Many jobs that today's students will have in 10 to 20 years haven't been invented yet. Professionals in every discipline—from artists and entertainers, to communications and health care professionals, to factory workers, small business owners, and retail store staff—need to understand computing to be productive and competitive in their fields. Thomas Friedman, in his best-selling book *The World is Flat* (2006), argues that our economy most needs "Versatilists," people who have expertise both in some domain and in technology. Computer science is the glue that makes it possible for Versatilists to bridge domain-specific expertise and technological innovation.

There is an unmistakable link between success, innovation, and computer science. Movies like *The Incredibles* and *Lord of the Rings* exemplify the creative use of new computing techniques. But it is hard to imagine any field that has not been impacted by computer science. Computing professionals are solving challenges in the sciences, business, art, and the humanities and creating new career opportunities in all of these fields.

Studying computer science can prepare a student to enter many career areas, both within and outside of computing. Professionals with computer science training have never been more in demand than they are today. Computing scientists are working with experts in other fields, designing and building computer systems that support the functioning of modern society and are enabling us to tackle the critical challenges that face our world. These challenges include global energy, healthcare, and world hunger. In addition, computing skills are now preferred, if not required, for work in almost any profession.

2.3 Computer Science Teaches Problem Solving

Computer scientists work closely with business people, scientists, artists, and other experts to understand the issues, and to define the problem so explicitly that it can be represented in a computer. This cooperative process requires people with different expertise and perspectives to work together to clarify the issues while considering each other's priorities and constraints.

Computer science teaches students to think about the problem-solving process itself. In computer science, the first step in solving a problem is to state it clearly and unambiguously. A computer scientist who helps to design a new computer system for a medical office, for example, has to take into account the current work

flow, patient privacy concerns, training needs for new staff, current and upcoming technology, and of course, the budget. Once the problem is well defined, a solution must be created. Computer hardware and peripheral devices must be selected or built. Computer programs must be designed, written, and tested. Existing software systems and packages may be modified and integrated into the final system. In all phases, the computer scientist thinks about reflective use of computer time and shared resources. Building a system is a creative process that also requires scientific thinking. With each fix of a bug or addition of a new feature, there's a hypothesis that the problem has been solved. Experiments are designed, data are collected, results are analyzed, and if the hypothesis is untrue, the cycle repeats.

A computer scientist is concerned with the robustness, the user-friendliness, the maintainability, and above all the correctness of computer solutions to business, scientific, and engineering problems. These issues often require both intense analysis and creativity. How will the system respond if the power goes out, or two nurses try to access the same patient record simultaneously, or the insurance company's system is changed, or someone enters unexpected data into the system? Cooperation is again the key. The users and clients have to think about how the system will be used in day-to-day life and anticipate its use in the future. Computer scientists draw on their training and experience to confront problems and to create the best possible solutions.

2.4 Computer Science Supports and Links to Other Sciences

To solve the big scientific problems of the 21st century, such as grappling with new diseases and climate change, we will need people with diverse skills, abilities, and perspectives. The sequencing of the human genome in 2001 was a landmark achievement of molecular biology, which would not have been possible without computer scientists. After short DNA fragments of the genome were sequenced in biology labs, computers were used to figure out how to piece the fragments together. This knowledge is paving the way for better computational methods of detecting and curing diseases, such as cancer, because we are now better able to simulate and hence understand the genetic mutations involved.

The human brain is complex and amazing. We know, for example, that an infant can effortlessly recognize a familiar face from many different viewpoints, and yet, we have a very poor understanding of the computational mechanisms that the brain uses to solve such tasks. Inferring meaning from images is a computational task, and computer scientists and neuroscientists are working together to figure out how to build computers that can process images and, ultimately, how we can better understand intelligence itself. The use of modeling and simulation, visualization, and management of massive data sets has fostered the emergence of a new field that bridges science, technology, engineering and math—computational science. This field integrates many aspects of computer science such as the design of algorithms and graphics with their application in the sciences.

In science classes, students use sophisticated simulation software to make molecules and geological processes come to life. Writing computer programs that model behavior allows scientists to generate results and test theories that are impossible to test in the physical world. Advances in weather prediction, for example, are largely dependent upon computer modeling and simulation. Computational methods have also transformed fields such as statistics and chemistry. Scientists who can understand and contribute to technological innovation have a huge advantage. Good training for future scientists must therefore include a solid basis in computer science.

2.5 Computer Science Can Engage All Students

Computer science applies to virtually every aspect of life, so that it can be easily tied to myriad student interests. For example, students who are fascinated with specific technologies such as cell phones may

have an innate passion for visual design, digital entertainment, or helping society. K–12 computer science teachers can thus nurture students' interests, passions, and sense of engagement with the world around them by offering opportunities for solving computational problems relevant to their own life experiences.

Excellence in computer science education relies on equitable practices that maximize the learning potential of all students. Computer science learning opportunities must be shaped in ways that connect the canon of computer science content provided in the curricular standards to the lived experiences of diverse students. The equitable practices in computer science education that connect students with the curriculum include:

- All students should have access to rigorous and culturally meaningful computer science and be held to high expectations for interacting with the curriculum.
- Diverse experiences, beliefs, and ways of knowing computer science should be acknowledged, incorporated, and celebrated in the classroom.
- The integration of different interpretations, strategies, and solutions that are computationally sound enhance classroom discussions and deepen understandings.
- The resources needed for teaching and learning computer science should be equitably allocated across groups of students, classrooms, and schools.
- Classroom learning communities should foster an environment in which all students are listened to, respected, and viewed as valuable contributors to the learning process.
- Ongoing teacher reflection about belief systems, assumptions, and biases support the development of equitable teaching practices.

Pedagogically, computer programming has the same relation to studying computer science as playing an instrument does to studying music or painting does to studying art. In each case, even a small amount of hands-on experience adds immensely to life-long appreciation and understanding, even if the student does not continue programming, playing, or painting as an adult. Although becoming an expert programmer, violinist, or oil painter demands much time and talent, we still want to expose every student to the joys of being creative. The goal for teaching computer science should be to get as many students as possible enthusiastically engaged with every assignment. We can provide students with the tools to design and write programs that control their cell phones or robots, create physics and biology simulations, or compose music. Students will want to learn to use conditionals, loops, parameters, and other fundamental concepts just to make these exciting things happen.

In a fast-paced field such as computer science, we are all challenged to keep up with our peers and our students. Technology changes rapidly, and students are sometimes more likely than teachers to be familiar with the latest incarnations. No teacher should be apprehensive of learning from her or his students. Real learning involves everyone in the room living with a sense of wonder and anticipation.

We know that teaching computer science involves some unique challenges and that none of us has all of the answers. The CSTA Source Web Repository at http://csta.acm.org/WebRepository/WebRepository.html provides a comprehensive collection of resources for teachers. These resources have been found to be helpful in our attempts to better interest, engage, and motivate our students. Not all of them will be completely applicable to every classroom, but we believe that many contain useful and varied suggestions that may inspire both students and teachers alike.

3. Defining the Terminology

Computer science is constantly being reshaped. New thinking and new technologies continue to expand our understanding of what computer scientists need to know. This has resulted in considerable debate concerning the definition of computer science itself.

Before discussing K–12 curriculum standards, we first therefore clarify the context in which the standards are set as well as address some of the confusion currently swirling around the proliferation of terms used to describe the various kinds of computing education.

For secondary school educators, perhaps the most profound confusion arises when trying to distinguish between the three most common areas of computing education offered in schools. While each of these areas has been known by various names, for the purposes of this discussion we call them:

- Educational Technology
- Information Technology, and
- Computer Science.

Educational Technology can be defined as using computers across the curriculum, or more specifically, using computer technology (hardware and software) to learn about other disciplines. For example, the science teacher may use pre-existing computer simulations to provide students with a better understanding of specific physics principles, or an English teacher may use word-processing software to help students improve their editing and revision skills. While educational technology is concerned with using these tools, *computer science* is concerned with designing, creating, testing, modifying, and verifying these tools.

Information technology (IT) is "the proper use of technologies by which people manipulate and share information in its various forms." While Information Technology involves learning about computers, it emphasizes the technology itself. Information Technology specialists assume responsibility for selecting appropriate hardware and software products, integrating those products with organizational needs and infrastructure, and installing, customizing, and maintaining those resources. Information Technology courses, therefore, focus on:

- installing, securing, and administering computer networks;
- installing, maintaining, and customizing software;
- managing and securing data in physical and virtual worlds;
- managing communication systems;
- designing, implementing, and managing Web resources; and
- developing and managing multimedia resources and other digital media.

IT is an applied field of study, driven by the practical benefits of its knowledge, while computer science adds scientific and mathematical, as well as practical, dimensions. Some of the practical dimensions of computer science are shared with IT, such as working with text, graphics, sound, and video. But while IT concentrates on learning how to use and apply these tools, computer science is concerned with learning how these tools are designed and why they work. Computer science and IT have a lot in common, but neither one is fully substitutable for the other. For example, the complexity of algorithms is a fundamental idea in computer science but would probably not appear in an IT curriculum.

Computer Science, on the other hand, spans a wide range of computing endeavors, from theoretical foundations to robotics, computer vision, intelligent systems, and bioinformatics. The work of computer scientists is concentrated in three areas:

- designing and implementing software,
- developing effective ways to solve computing problems, and
- devising new ways to use computers.

For the purposes of this document, we rely heavily on the definition of computer science provided in the original *ACM/CSTA Model Curriculum for K–12 Computer Science*, as we believe that this definition of computer science has the most direct relevance to high school computer science education.

"*Computer science (CS)* is the study of computers and algorithmic processes, including their principles,

their hardware and software designs, their applications, and their impact on society."

A basic understanding of computer science is now an essential ingredient to preparing high school graduates for life in the 21st century, and the goals of any rigorous computer science course should be to:

- introduce the fundamental concepts of computer science to all students, beginning at the elementary school level,
- present computer science at the secondary school level in a way that would be both accessible and worthy of an academic curriculum credit (e.g., math or science),
- offer additional secondary-level computer science courses that will allow interested students to study it in depth and prepare them for entry into the work force or college, and
- increase the knowledge of computer science for all students, especially those who are members of historically underrepresented groups in computer science.

Two other terms that often appear in discussions of computing education are *Information Technology Literacy* and *Information Technology Fluency*. A National Academy study published in 1999, defines *IT fluency* as something more comprehensive than *IT literacy*. Whereas *IT literacy* is the capability to use *today's* technology in one's own field, the notion of IT fluency adds the capability to independently *learn* and use *new* technology as it evolves throughout one's professional lifetime. Moreover, *IT fluency* also includes the active use of *computational thinking* (including programming) to solve problems, whereas *IT literacy* does not. *Computational thinking* is an approach to solving problems in a way that can be implemented with a computer. It involves the use of concepts, such as abstraction, recursion, and iteration, to process and analyze data, and to create real and virtual artifacts.

IT fluency was proposed as a minimum standard that all college students should achieve by the time they graduate. Most colleges and universities have implemented these or similar standards and are expecting their graduates to achieve them. In this document, we strongly support the contention that this minimum standard should be implemented at the K–12 level as well.

4. Organization of the Learning Outcomes: Levels and Strands

We propose a three-level model for K–12 computer science that addresses the needs of the present and future by building on the lessons of the past. It focuses on fundamental concepts with the following general goals:

1. The curriculum should prepare students to understand the nature of computer science and its place in the modern world.
2. Students should understand that computer science interweaves concepts and skills.
3. Students should be able to use computer science skills (especially computational thinking) in their problem-solving activities in other subjects.
4. The computer science standards should complement IT and AP computer science curricula in schools where they are currently offered.

If these standards are widely implemented and these goals are met, high school graduates will be prepared to be knowledgeable users and critics of computers, as well as designers and builders of computing applications that will affect every aspect of life in the 21st century.

4.1 Levels

The CSTA Standards for K–12 computer science are based on a model where each of the three levels represent a specific set of grades and courses. Level 1 provides the learning standards for students in Grades K–6, Level 2 provides the learning standards for stu-

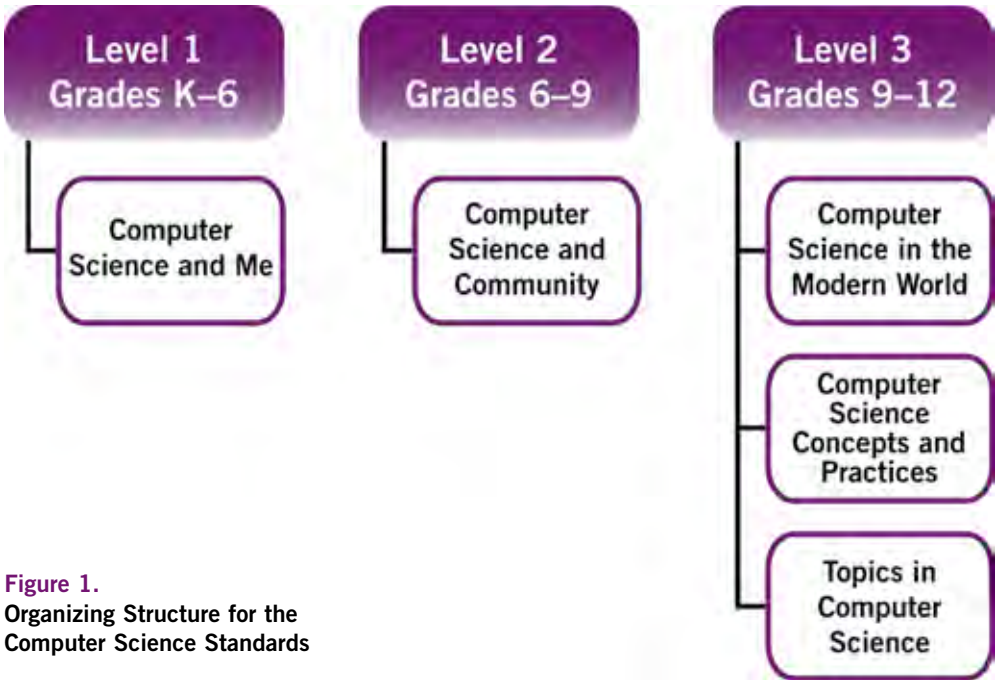

Figure 1.
Organizing Structure for the Computer Science Standards

dents in Grades 6–9, and Level 3 provides the learning standards for students in each of three discrete courses in grades 9–12. (We note that the boundaries specified for each Level will vary from school to school.) The overall structure of this model is shown in Figure 1.

Level 1 (recommended for grades K–6) Computer Science and Me: Elementary school students are introduced to foundational concepts in computer science by integrating basic skills in technology with simple ideas about computational thinking. The learning experiences created from these standards should be inspiring and engaging, helping students see computing as an important part of their world. They should be designed with a focus on active learning, creativity, and exploration and will often be embedded within other curricular areas such as social science, language arts, mathematics, and science.

Level 2 (recommended for grades 6–9) Computer Science and Community: Middle school/junior high school students begin using computational thinking as a problem-solving tool. They begin to appreciate the ubiquity of computing and the ways in which computer science facilitates communication and collaboration. Students begin to experience computational thinking as a means of addressing issues relevant, not just to them, but to the world around them. The learning experiences created from these standards should be relevant to the students and should promote their perceptions of themselves as proactive and empowered problem solvers. They should be designed with a focus on active learning and exploration and can be taught within explicit computer science courses or embedded in other curricular areas such as social science, language arts, mathematics, and science.

Level 3 (recommended for grades 9–12) Applying concepts and creating real-world solutions: Level 3 is divided into three discrete courses, each of which focuses on different facets of computer science as a discipline. Throughout these courses, students can master more advanced computer science concepts and apply those concepts to develop virtual and real-world artifacts. The learning experiences created from these standards should focus on the exploration of real-world problems and the application of computational thinking to the development of solutions. They should be designed with a focus on collaborative learning, project management, and effective communication. Level 3 includes the following courses:

Level 3A: (recommended for grades 9 or 10) *Computer Science in the Modern World:* This course is recommended for all students. Its goal is to solidify students' understanding of computer science principles and practices so that they can make informed choices and use appropriate computational tools and techniques in whatever career they decide to pursue. They should also appreciate the breadth of computing and its influence in almost every aspect of modern life. Finally, they should understand the social and ethical impact of their various choices when using computing technology in their work and personal lives and the choices that have already been made for them by those who develop the technologies they use.

Level 3B: (recommended for grades 10 or 11) *Computer Science Concepts and Practices:* This course is a more in-depth study of computer science and its relation to other disciplines, and contains a significant amount of algorithmic problem solving and related activities. One way to realize this course is by following the Computer Science Principles course (www.apcsprinciples.org). Students should complete this course with a clear understanding of the application of computational thinking to real-world problems. They should also have learned how to work collaboratively to solve a problem and use modern collaboration tools during that work.

Level 3C: (recommended for grades 11 or 12) *Topics in Computer Science:* This is an elective course that provides depth of study in one particular area of computing. This may be, for example, an AP Computer Science A (AP, 2010) course, which offers depth of study in Java programming. Alternatively, this offering may be a projects-based course focusing on a single facet of computing or a course that leads to professional computing certification.

4.2 Strands

Almost since its inception, computer science has been hampered by the perception that it focuses exclusively on programming. This misconception has been particularly damaging in grades K–12 where it often has led to courses that were exceedingly limited in scope and negatively perceived by students. It also fed into other unfortunate perceptions of computer science as a solitary pursuit, disconnected from the rest of the world and of little relevance to the interests and concerns of students.

We address these concerns by distinguishing five complementary and essential strands throughout all three levels in these standards. These strands are: computational thinking; collaboration; computing practice; computers and communication devices; and community, global, and ethical impacts. These strands not only demonstrate the richness of computer science but also help organize the subject matter for students so that they can begin to perceive computer science as more engaging and relevant, and as more than a solitary pursuit. Figure 2 shows these strands graphically.

The following subsections discuss how these five strands can help students enrich their understanding and mastery of computer science during their formative years. More detailed discussions appear later in this report.

4.2.1 Computational Thinking

We believe that computational thinking (CT) can be used across all disciplines to solve problems, design systems, create new knowledge, and improve understanding of the power and limitations of computing in the modern age. The study of computational thinking enables all students to better conceptualize, analyze, and solve complex problems by selecting and applying appropriate strategies and tools, both virtually and in the real world.

K–12 education is a highly complex, highly politicized environment where multiple competing priorities, ideologies, pedagogies, and ontologies all vie for attention. It is also subject to widely diverse expectations, intense scrutiny, and diminishing resources. Any effort to achieve systemic change in this environment requires a deep understanding of these realities. Passionate debate about the nature of computer

Figure 2.
Strands in the Computer Science Standards

science or computational thinking may provide intellectual stimulation for those in the computing fields. However, embedding computational thinking in grades K–12 requires a practical approach, grounded in an operational definition.

Developing an approach to computational thinking that is suitable for K–12 students is especially challenging in light of the fact that there is, as yet, no widely agreed upon definition of *computational thinking*. For the purposes of this document, we rely upon the definition developed during a series of workshops hosted by the International Society for Technology in Education (ISTE) and the Computer Science Teachers Association (CSTA) and reported by Barr and Stephenson (2011):

"CT is an approach to solving problems in a way that can be implemented with a computer. Students become not merely tool users but tool builders. They use a set of concepts, such as abstraction, recursion, and iteration, to process and analyze data, and to create real and virtual artifacts. CT is a problem-solving methodology that can be automated and transferred and applied across subjects. The power of computational thinking is that it applies to every other type of reasoning. It enables all kinds of things to get done: quantum physics, advanced biology, human–computer systems, development of useful computational tools."

Computational thinking is thus a problem-solving methodology that can interweave computer science with all disciplines, providing a distinctive means of analyzing and developing solutions to problems that can be solved computationally. With its focus on abstraction, automation, and analysis, computational thinking is a core element of the broader discipline of computer science and for that reason it is interwoven through these computer science standards at all levels of K–12 learning.

4.2.2 Collaboration

Computer science is an intrinsically collaborative discipline. Significant progress is rarely made in computer science by one person working alone. Typically, computing projects involve large teams of computing professionals working together to design, code, test, debug, describe, and maintain software over time. New programming methodologies such as pair programming emphasize the importance of working together. Additionally, development teams working with discipline-specific experts ensure the computational solutions are appropriate, effective,

and efficient. Developing collaboration skills is thus an important part of these K–12 national computer science standards.

In elementary school, students can begin to work cooperatively with fellow students and teachers using technology. They learn to gather information and communicate with others using a variety of traditional and mobile communication devices. They also learn to use online resources and participate in collaborative problem solving activities. These collaborative activities continue into middle school, where students apply multimedia and productivity tools for group learning exercises. In secondary school, students enhance their collaborative abilities by participating in teams to solve software problems that are relevant to their daily lives. Skills learned at this level can include teamwork, constructive criticism, project planning and management, and team communication, all of which are considered necessary 21st Century skills (see Partnership for 21st Century Skills at p21.org).

4.2.3 Computing Practice and Programming

The use of computational tools is an essential part of computer science education at all levels. While this is traditionally branded as "Information Technology," it is impossible to separate IT from the other four strands in computer science. Computing practice at the K–12 level must therefore include the ability to create and organize webpages, explore the use of programming in solving problems, select appropriate file and database formats for a particular computational problem, and use appropriate Application Program Interfaces (APIs), software tools, and libraries to help solve algorithmic and computational problems.

By the time they reach high school and are selecting career or educational paths, students should be well informed about their options so that they can make intelligent decisions. K–12 students must therefore be introduced to the variety of careers that exist in computing or to which computing makes a significant contribution. Because computing is often misperceived as only programming, it is especially important for students to understand the broad array of opportunities computer science knowledge can provide across every field and discipline.

4.2.4 Computer and Communications Devices

K–12 students at all levels should understand the elements of modern computer and communication devices and networks. They should also understand how the Internet facilitates global communication and how to practice good Internet citizenship. Students should also use appropriate and accurate terminology when communicating about technology

At the elementary school level, students are introduced to many devices and media that can assist them with their learning activities, both within computer science and in other disciplines. Middle school students begin discriminating among different devices and their uses. They should also be able to describe the basic components of computers and computer networks. For instance, they should understand the organization of webpages, URLs, and search engines. Secondary school students should understand computational devices in more detail, learning to form abstract ideas about specific components (e.g., input, output, processors, and databases) and their roles in the computational spectrum. Students should also understand why a compiler translates software into a machine-executable form.

4.2.5 Community, Global, and Ethical Impacts

The ethical use of computers and networks is a fundamental aspect of computer science at all levels and should be seen as an essential element of both learning and practice. As soon as students begin using the Internet, they should learn the norms for its ethical use. Principles of personal privacy, network security, software licenses, and copyrights must be taught at an appropriate level in order to prepare students to become responsible citizens in the modern world. Students should be able to make informed and ethical choices among various types of software such as proprietary and open source and understand the importance of adhering to the licensing or use agree-

ments. Students should also be able to evaluate the reliability and accuracy of information they receive from the Internet.

Computers and networks are a multicultural phenomenon that effect society at all levels. It is essential that K–12 students understand the impact of computers on international communication. They should learn the difference between appropriate and inappropriate social networking behaviors. They should also appreciate the role of adaptive technology in the lives of people with various disabilities.

Computing, like all technologies, has a profound impact on any culture into which it is placed. The distribution of computing resources in a global economy raises issues of equity, access, and power. Social and economic values influence the design and development of computing innovations. Students should be prepared to evaluate the various positive and negative impacts of computers on society and to identify the extent to which issues of access (who has access, who does not, and who makes the decisions about access) impact our lives.

5. Comprehensive Computer Science Standards for K–12

Drawing from the understandings and contexts described in earlier sections, this section defines new standards for K–12 computer science education, presenting them in a learning objective-based format that identifies the specific computer science concepts and skills students should achieve at each of the three levels (grades K–6, 6–9, and 9–12).

5.1 Level 1: Computer Science and Me (L1)

These standards introduce elementary school students to foundational concepts in computer science by integrating basic skills in technology with basic concepts about computational thinking. The learning experiences created from these standards should be inspiring and engaging, helping students see computing as an important part of their world. They should be designed with a focus on active learning, creativity, and exploration and will typically be embedded within other curricular areas such as social science, language arts, mathematics, and science.

It is important to recognize the significant impact that an early exposure to the five strands described in the previous section can have as students progress toward higher level computer science programs. K–6 students need to learn how computing tools can be used to help solve problems, communicate with others, and access and organize information by themselves or in collaboration with others. They need to begin to explore issues concerning the validity and value of different information sources. They must also learn to be responsible citizens in the ever-changing digital world. Ethical and safe uses of computers and networks should be introduced to even our youngest students.

We agree with teachers who believe that students at this age ought to begin thinking algorithmically as a general problem-solving strategy. Thus, it makes sense to develop more teaching strategies that encourage students to engage in the process of visualizing or acting out an algorithm. Seymour Papert's pioneering experiments in the 1970s corroborate this belief, and his seminal work *Mindstorms* and related curricula provide many more examples of how elementary students can be engaged in algorithmic thinking. This engagement can be accomplished with or without the use of computing devices as in the following examples:

- finding your way out of a maze (Turtle graphics, robotics),
- a dog retrieving a thrown ball,
- baking cookies,
- going home from school,
- making a sand castle, and
- arranging a list of words in alphabetical order.

Any of the activities designed to introduce K–6 students to the five strands can involve individuals

working alone or in collaboration with their peers. The concept of "team" is one that can be introduced at any grade level. Students working together can find multiple solutions to problems utilizing the resources available through online searches and then create multimedia presentations as a way of demonstrating their chosen solution. As they are developing these skills, they can start to become more aware of the many tools and programs that can be used to communicate with each other, their teachers, their parents, and even students in far away places. They will begin to think about how computers and programs work together to make things happen as they do.

As K–6 students are exposed to the many facets of communications and social networking through technology, it is essential that they learn the safe and ethical way to use these tools and the potential repercussions of their improper use. They can explore the many ways in which computing devices and technology impact their lives and the society around them.

Following are the standards that all students in Grades K–6 should meet in the five strands:

Computational Thinking: (CT)

Grades K–3 (L1:3.CT)
The student will be able to:

1. Use technology resources (e.g., puzzles, logical thinking programs) to solve age-appropriate problems.
2. Use writing tools, digital cameras, and drawing tools to illustrate thoughts, ideas, and stories in a step-by-step manner.
3. Understand how to arrange (sort) information into useful order, such as sorting students by birth date, without using a computer.
4. Recognize that software is created to control computer operations.
5. Demonstrate how 0s and 1s can be used to represent information.

Grades 3–6 (L1:6.CT)
The student will be able to:

1. Understand and use the basic steps in algorithmic problem-solving (e.g., problem statement and exploration, examination of sample instances, design, implementation, and testing).
2. Develop a simple understanding of an algorithm (e.g., search, sequence of events, or sorting) using computer-free exercises.
3. Demonstrate how a string of bits can be used to represent alphanumeric information.
4. Describe how a simulation can be used to solve a problem.
5. Make a list of sub-problems to consider while addressing a larger problem.
6. Understand the connections between computer science and other fields.

Collaboration (CL)

Grades K–3 (L1:3.CL)
The student will be able to:

1. Gather information and communicate electronically with others with support from teachers, family members, or student partners.
2. Work cooperatively and collaboratively with peers, teachers, and others using technology.

Grades 3–6 (L1:6.CL)
The student will be able to:

1. Use productivity technology tools (e.g., word processing, spreadsheet, presentation software) for individual and collaborative writing, communication, and publishing activities.
2. Use online resources (e.g., email, online discussions, collaborative web environments) to participate in collaborative problem-solving activities for the purpose of developing solutions or products.

3. Identify ways that teamwork and collaboration can support problem solving and innovation.

Computing Practice and Programming (CPP)

Grades K–3 (L1:3.CPP)
The student will be able to:

1. Use technology resources to conduct age-appropriate research.
2. Use developmentally appropriate multimedia resources (e.g., interactive books and educational software) to support learning across the curriculum.
3. Create developmentally appropriate multimedia products with support from teachers, family members, or student partners.
4. Construct a set of statements to be acted out to accomplish a simple task (e.g., turtle instructions).
5. Identify jobs that use computing and technology.
6. Gather and organize information using concept-mapping tools.

Grades 3–6 (L1:6.CPP)
The student will be able to:

1. Use technology resources (e.g., calculators, data collection probes, mobile devices, videos, educational software, and web tools) for problem-solving and self-directed learning.
2. Use general-purpose productivity tools and peripherals to support personal productivity, remediate skill deficits, and facilitate learning.
3. Use technology tools (e.g., multimedia and text authoring, presentation, web tools, digital cameras, and scanners) for individual and collaborative writing, communication, and publishing activities.
4. Gather and manipulate data using a variety of digital tools.
5. Construct a program as a set of step-by-step instructions to be acted out (e.g., make a peanut butter and jelly sandwich activity).
6. Implement problem solutions using a block-based visual programming language.
7. Use computing devices to access remote information, communicate with others in support of direct and independent learning, and pursue personal interests.
8. Navigate between webpages using hyperlinks and conduct simple searches using search engines.
9. Identify a wide range of jobs that require knowledge or use of computing.
10. Gather and manipulate data using a variety of digital tools.

Computers and Communications Devices (CD)

Grades K–3 (L1:3.CD)
The student will be able to:

1. Use standard input and output devices to successfully operate computers and related technologies.

Grades 3–6 (L1:6.CD)
The student will be able to:

1. Demonstrate an appropriate level of proficiency with keyboards and other input and output devices.
2. Understand the pervasiveness of computers and computing in daily life (e.g., voice mail, downloading videos and audio files, microwave ovens, thermostats, wireless Internet, mobile computing devices, GPS systems).
3. Apply strategies for identifying simple hardware and software problems that may occur during use.
4. Identify that information is coming to the computer from many sources over a network.
5. Identify factors that distinguish humans from machines.

6. Recognize that computers model intelligent behavior (as found in robotics, speech and language recognition, and computer animation).

Community, Global, and Ethical Impacts (CI)

Grades K–3 (L1:3.CI)
The student will be able to:

1. Practice responsible digital citizenship (legal and ethical behaviors) in the use of technology systems and software.
2. Identify positive and negative social and ethical behaviors for using technology.

Grades 3–6 (L1:6.CI)
The student will be able to:

1. Discuss basic issues related to responsible use of technology and information, and the consequences of inappropriate use.
2. Identify the impact of technology (e.g., social networking, cyber bullying, mobile computing and communication, web technologies, cyber security, and virtualization) on personal life and society.
3. Evaluate the accuracy, relevance, appropriateness, comprehensiveness, and biases that occur in electronic information sources.
4. Understand ethical issues that relate to computers and networks (e.g., equity of access, security, privacy, copyright, and intellectual property).

5.2 Level 2: Computer Science and Community (L2)

The learning expectations covered by these standards support middle school/junior high school students in the use of computational thinking as a problem-solving tool. They begin to appreciate the ubiquity of computing and the ways in which computer science facilitates communication and collaboration. Students begin to experience computational thinking as a means of addressing issues relevant, not just to them, but to the world around them. The learning experiences created from these standards should be relevant to the students and should promote their perceptions of themselves as proactive and empowered problem solvers within their community. They should be designed with a focus on active learning and exploration that can be taught either as an explicit computer science course or as units embedded in other curricular areas such as social science, language arts, mathematics, and science.

The Level 2 curriculum standards assume that students already have been introduced to the computational thinking concepts of data representation, algorithms, and problem solving; and that they have had experience using technology tools and resources for learning, creating digital artifacts, and collaborating. Students should also have learned about the many careers that use computing and technology, standard input/outut devices and computers, basic computer terminology, and the principles of acting responsibly and ethically when using computers independently and working with others.

Lower secondary school students are developing socially and emotionally. They interact in larger social spheres than elementary students and are transitioning from a focus on self to group-oriented behaviors. Their social spheres are growing beyond the nuclear family to include fellow students, peer groups, teachers, coaches and other community members. Acknowledging these shifts, the focus at Level 2 is on using computers and computation as both individuals and community members. In this way, students begin to experience computational thinking as a means of communicating with others and as a means to address community-relevant issues.

The goals of the Level 2 curriculum are to engage students in using computational thinking as a problem-solving tool, teach them to use programming concepts and methods while creating digital artifacts,

and retain their interest in computing as a relevant and exciting field. Learning opportunities should be presented in ways that are active, connected, and relevant to them, and should promote the perception of themselves as proactive and empowered problem solvers, creators, and innovators capable of changing the world. Collaborative learning experiences at this level should prepare students to work in teams and to build supportive partnerships.

As students begin to master fundamental computer science concepts and practices, it is vitally important that they learn that these concepts and practices empower them to create innovations, tools, and applications. Students should also know that with this knowledge and access comes responsibility, so issues of ethical and responsible use of computing and information are also essential elements of this curriculum.

Here are the standards that all students in Grades 6–9 should meet in the five strands:

Computational Thinking: (CT)

The student will be able to:

1. Use the basic steps in algorithmic problem-solving to design solutions (e.g., problem statement and exploration, examination of sample instances, design, implementing a solution, testing, evaluation).
2. Describe the process of parallelization as it relates to problem solving.
3. Define an algorithm as a sequence of instructions that can be processed by a computer.
4. Evaluate ways that different algorithms may be used to solve the same problem.
5. Act out searching and sorting algorithms.
6. Describe and analyze a sequence of instructions being followed (e.g., describe a character's behavior in a video game as driven by rules and algorithms).
7. Represent data in a variety of ways including text, sounds, pictures, and numbers.
8. Use visual representations of problem states, structures, and data (e.g., graphs, charts, network diagrams, flowcharts).
9. Interact with content-specific models and simulations (e.g., ecosystems, epidemics, molecular dynamics) to support learning and research.
10. Evaluate what kinds of problems can be solved using modeling and simulation.
11. Analyze the degree to which a computer model accurately represents the real world.
12. Use abstraction to decompose a problem into sub problems.
13. Understand the notion of hierarchy and abstraction in computing including high-level languages, translation, instruction set, and logic circuits.
14. Examine connections between elements of mathematics and computer science including binary numbers, logic, sets and functions.
15. Provide examples of interdisciplinary applications of computational thinking.

Collaboration (CL)

The student will be able to:

1. Apply productivity/multimedia tools and peripherals to group collaboration and support learning throughout the curriculum.
2. Collaboratively design, develop, publish, and present products (e.g., videos, podcasts, websites) using technology resources that demonstrate and communicate curriculum concepts.
3. Collaborate with peers, experts, and others using collaborative practices such as pair programming, working in project teams, and participating in group active learning activities.
4. Exhibit dispositions necessary for collaboration: providing useful feedback, integrating feedback, understanding and accepting multiple perspectives, socialization.

Computing Practice & Programming (CPP)

The student will be able to:

1. Select appropriate tools and technology resources to accomplish a variety of tasks and solve problems.
2. Use a variety of multimedia tools and peripherals to support personal productivity and learning throughout the curriculum.
3. Design, develop, publish, and present products (e.g., webpages, mobile applications, animations) using technology resources that demonstrate and communicate curriculum concepts.
4. Demonstrate an understanding of algorithms and their practical application.
5. Implement problem solutions using a programming language, including: looping behavior, conditional statements, logic, expressions, variables, and functions.
6. Demonstrate good practices in personal information security, using passwords, encryption, and secure transactions.
7. Identify interdisciplinary careers that are enhanced by computer science.
8. Demonstrate dispositions amenable to open-ended problem solving and programming (e.g., comfort with complexity, persistence, brainstorming, adaptability, patience, propensity to tinker, creativity, accepting challenge).
9. Collect and analyze data that is output from multiple runs of a computer program.

Computers & Communications Devices (CD)

The student will be able to:

1. Recognize that computers are devices that execute programs.
2. Identify a variety of electronic devices that contain computational processors.
3. Demonstrate an understanding of the relationship between hardware and software.
4. Use developmentally appropriate, accurate terminology when communicating about technology.
5. Apply strategies for identifying and solving routine hardware problems that occur during everyday computer use.
6. Describe the major components and functions of computer systems and networks.
7. Describe what distinguishes humans from machines focusing on human intelligence versus machine intelligence and ways we can communicate.
8. Describe ways in which computers use models of intelligent behavior (e.g., robot motion, speech and language understanding, and computer vision).

Community, Global, and Ethical Impacts (CI)

The student will be able to:

1. Exhibit legal and ethical behaviors when using information and technology and discuss the consequences of misuse.
2. Demonstrate knowledge of changes in information technologies over time and the effects those changes have on education, the workplace, and society.
3. Analyze the positive and negative impacts of computing on human culture.
4. Evaluate the accuracy, relevance, appropriateness, comprehensiveness, and bias of electronic information sources concerning real-world problems.
5. Describe ethical issues that relate to computers and networks (e.g., security, privacy, ownership, and information sharing).
6. Discuss how the unequal distribution of computing resources in a global economy raises issues of equity, access, and power.

5.3 Level 3: Applying Concepts and Creating Real-World Solutions (L3)

Level 3 is divided into three discrete courses, each of which focuses on a different aspect of computer sci-

ence as a discipline. Throughout these courses, students will learn advanced computer science concepts and apply those concepts to develop virtual and real-world artifacts. The learning experiences created from these standards should focus on the exploration of real-world problems, the application of computational thinking to the development of problem solutions, and the interconnections between computer science and other academic subjects. These experiences should also include a focus on collaborative learning and effective communication.

Level 3 includes the following courses:

3A: Computer Science in the Modern World (MW)
3B: Computer Science Principles (CP)
3C: Topics in Computer Science (TO)

Normally, course 3A will be a prerequisite for either of the other two. The following sections describe these three courses in more detail. These courses have been designed under the assumption that they are year-long courses. Schools unable to offer them as year-long courses may need to adjust the number of standards that can be covered.

5.3.A *Computer Science in the Modern World (MW)*

Computer Science in the Modern World is a course designed to expose all students to the interdisciplinary nature of computer science in today's dynamic and globally connected society. Students will have the opportunity to explore the uses of computer science as a tool in creating effective solutions to complex contemporary problems. The hands-on nature of the course is intended to provide students with the opportunity to explore conceptual understanding in a practical learning environment. This course is recommended for all students as it provides an overview of computer sciences and its applications in various disciplines, professions, and personal activities.

In this course, students will learn to use computational thinking to develop algorithmic solutions to real-world problems. They will begin to understand the different levels of complexity in problem solving and to determine when team projects might generate more effective problem solutions than individual efforts. Students will learn and use a programming language(s) and related tools, as well as appropriate collaboration tools, computing devices, and network environments. Finally, they will demonstrate an understanding of the social and ethical implications of their work and exhibit appropriate communication behavior when working as a team member.

Computer Science in the Modern World is a course designed for all students at the 9th and 10th grade levels. This course is built around the essential skills that all high school students should have upon graduation. It also provides the necessary skills needed for more advanced studies at levels 3.B and 3.C. It is recommended that this course be required of all students.

Computational Thinking (CT)

The student will be able to:

1. Use predefined functions and parameters, classes and methods to divide a complex problem into simpler parts.
2. Describe a software development process used to solve software problems (e.g., design, coding, testing, verification).
3. Explain how sequence, selection, iteration, and recursion are building blocks of algorithms.
4. Compare techniques for analyzing massive data collections.
5. Describe the relationship between binary and hexadecimal representations.
6. Analyze the representation and trade-offs among various forms of digital information.
7. Describe how various types of data are stored in a computer system.
8. Use modeling and simulation to represent and understand natural phenomena.
9. Discuss the value of abstraction to manage problem complexity.

10. Describe the concept of parallel processing as a strategy to solve large problems.
11. Describe how computation shares features with art and music by translating human intention into an artifact.

Collaboration (CL)

The student will be able to:

1. Work in a team to design and develop a software artifact.
2. Use collaborative tools to communicate with project team members (e.g., discussion threads, wikis, blogs, version control, etc.).
3. Describe how computing enhances traditional forms and enables new forms of experience, expression, communication, and collaboration
4. Identify how collaboration influences the design and development of software products.

Computing Practice and Programming (CPP)

The student will be able to:

1. Create and organize Web pages through the use of a variety of web programming design tools.
2. Use mobile devices/emulators to design, develop, and implement mobile computing applications.
3. Use various debugging and testing methods to ensure program correctness (e.g., test cases, unit testing, white box, black box, integration testing)
4. Apply analysis, design, and implementation techniques to solve problems (e.g., use one or more software lifecycle models).
5. Use Application Program Interfaces (APIs) and libraries to facilitate programming solutions.
6. Select appropriate file formats for various types and uses of data.
7. Describe a variety of programming languages available to solve problems and develop systems.
8. Explain the program execution process.
9. Explain the principles of security by examining encryption, cryptography, and authentication techniques.
10. Explore a variety of careers to which computing is central.
11. Describe techniques for locating and collecting small and large-scale data sets.
12. Describe how mathematical and statistical functions, sets, and logic are used in computation.

Computers and Communications Devices (CD)

The student will be able to:

1. Describe the unique features of computers embedded in mobile devices and vehicles (e.g., cell phones, automobiles, airplanes).
2. Develop criteria for purchasing or upgrading computer system hardware.
3. Describe the principal components of computer organization (e.g., input, output, processing, and storage).
4. Compare various forms of input and output.
5. Explain the multiple levels of hardware and software that support program execution (e.g., compilers, interpreters, operating systems, networks).
6. Apply strategies for identifying and solving routine hardware and software problems that occur in everyday life.
7. Compare and contrast client-server and peer-to-peer network strategies.
8. Explain the basic components of computer networks (e.g., servers, file protection, routing, spoolers and queues, shared resources, and fault-tolerance).
9. Describe how the Internet facilitates global communication.
10. Describe the major applications of artificial intelligence and robotics.

Community, Global, and Ethical Impacts (CI)

The student will be able to:

1. Compare appropriate and inappropriate social networking behaviors.
2. Discuss the impact of computing technology on business and commerce (e.g., automated tracking of goods, automated financial transactions, e-commerce, cloud computing).
3. Describe the role that adaptive technology can play in the lives of people with special needs.
4. Compare the positive and negative impacts of technology on culture (e.g., social networking, delivery of news and other public media, and intercultural communication).
5. Describe strategies for determining the reliability of information found on the Internet.
6. Differentiate between information access and information distribution rights.
7. Describe how different kinds of software licenses can be used to share and protect intellectual property.
8. Discuss the social and economic implications associated with hacking and software piracy.
9. Describe different ways in which software is created and shared and their benefits and drawbacks (commercial software, public domain software, open source development).
10. Describe security and privacy issues that relate to computer networks.
11. Explain the impact of the digital divide on access to critical information.

5.3.B *Computer Science Concepts and Practices (CP)*

Computer Science Concepts and Practices is a follow-up course to *Computer Science in the Modern World*. It is designed to harness the interests of those students wishing to further enhance their studies in the computing fields. In this course, students will begin to develop higher-level computing skills and apply them to a variety of subjects and disciplines. Students will learn how computer science impacts society and promotes change. Through the analysis of global issues, students will explore how computer science can help solve real-world problems using innovation, collaboration, and creativity. This course will also provide students with an opportunity to explore Computer Science as a potential career interest at the collegiate level.

In both its content and pedagogy, this course aims to appeal to a broad audience. In this course, students will begin to understand the central ideas of computing and computer science, focusing on the concepts and practices of computational and critical thinking and engaging in activities that show how computer science is helping to change the world. This rigorous course also engages students in the creative aspects of computer science.

Computer Science Concepts and Practices is designed as an elective course geared toward students in grades 10 through 12. Students enrolled in this course should have previously completed *Computer Science in the Modern World*. Due to its mathematical content, students should also have completed at least Algebra I. This course should nevertheless be accessible to all students. Students with special interests in a concentrated area of computer science (such as networking, programming, game design, etc.) can continue their exploration through the courses outlined in Level 3.C: *Topics in Computer Science*.

Computational Thinking (CT)

The student will be able to:

1. Classify problems as tractable, intractable, or computationally unsolvable.
2. Explain the value of heuristic algorithms to approximate solutions for intractable problems.
3. Critically examine classical algorithms and implement an original algorithm.
4. Evaluate algorithms by their efficiency, correctness, and clarity.

5. Use data analysis to enhance understanding of complex natural and human systems.
6. Compare and contrast simple data structures and their uses (e.g., arrays and lists).
7. Discuss the interpretation of binary sequences in a variety of forms (e.g., instructions, numbers, text, sound, image).
8. Use models and simulations to help formulate, refine, and test scientific hypotheses.
9. Analyze data and identify patterns through modeling and simulation.
10. Decompose a problem by defining new functions and classes.
11. Demonstrate concurrency by separating processes into threads and dividing data into parallel streams.

Collaboration (CL)

The student will be able to:

1. Use project collaboration tools, version control systems, and Integrated Development Environments (IDEs) while working on a collaborative software project.
2. Demonstrate the software life cycle process by participating on a software project team.
3. Evaluate programs written by others for readability and usability.

Computing Practice and Programming (CPP)

The student will be able to:

1. Use advanced tools to create digital artifacts (e.g., web design, animation, video, multimedia).
2. Use tools of abstraction to decompose a large-scale computational problem (e.g., procedural abstraction, object-oriented design, functional design).
3. Classify programming languages based on their level and application domain
4. Explore principles of system design in scaling, efficiency, and security.
5. Deploy principles of security by implementing encryption and authentication strategies.
6. Anticipate future careers and the technologies that will exist.
7. Use data analysis to enhance understanding of complex natural and human systems.
8. Deploy various data collection techniques for different types of problems.

Computers and Communications Devices (CD)

The student will be able to:

1. Discuss the impact of modifications on the functionality of application programs.
2. Identify and describe hardware (e.g., physical layers, logic gates, chips, components).
3. Identify and select the most appropriate file format based on trade-offs (e.g., accuracy, speed, ease of manipulation).
4. Describe the issues that impact network functionality (e.g., latency, bandwidth, firewalls, server capability).
5. Explain the notion of intelligent behavior through computer modeling and robotics.

Community, Global, and Ethical Impacts (CI)

The student will be able to:

1. Demonstrate ethical use of modern communication media and devices.
2. Analyze the beneficial and harmful effects of computing innovations.
3. Summarize how financial markets, transactions, and predictions have been transformed by automation.
4. Summarize how computation has revolutionized the way people build real and virtual organizations and infrastructures.
5. Identify laws and regulations that impact the development and use of software.
6. Analyze the impact of government regulation on privacy and security.

7. Differentiate among open source, freeware, and proprietary software licenses and their applicability to different types of software.
8. Relate issues of equity, access, and power to the distribution of computing resources in a global society.

5.3.C *Topics in Computer Science (TO)*

At this level, interested and qualified students should be able to select one from among several electives to gain depth of understanding or special skills in particular areas of computer science. All of these electives will require the Level 3A course as a prerequisite, while some may require the Level 3B course as well. Most important, these courses provide students with an opportunity to explore topics of personal interest in greater depth, and thus prepare for the workplace or for further study at the post-secondary level.

These electives include, but are not necessarily limited to:

- Advanced Placement (AP) Computer Science A,
- A projects-based course in which students cover a topic in depth,
- A vendor-supplied course, which may be related to professional certification.

These alternatives are discussed in more detail below.

5.3.C.1 *AP Computer Science A*

The Advanced Placement Computer Science curriculum is well established (AP, 2010), and is offered at many secondary schools for students planning to continue their education in a two- or four-year college or university, possibly in computer science, business, or a related field. The AP Computer Science A course emphasizes problem solving and algorithm development, and introduces elementary data structures. Students who complete this course and score well on the exam may qualify for one-semester of college credit. Students taking the AP Computer Science A course should have completed Levels 1, 2, and 3A. That is, they need to be familiar with the computational/algorithmic concepts introduced at those levels. The Level 3B course provides an excellent foundation in computer science principles and may also be useful for students intending to take the AP Computer Science A course.

5.3.C.2 *Projects-Based Courses*

A projects-based course would be available to all students who have completed the Level 1 and Level 2 courses. Most project-based courses will also require completion of the Level 3A course. Some variants of this course would also require completion of the Level 3B course. A project-based course can be either a half-year or a full-year course.

The projects in this kind of course will naturally reflect diverse student interests and specific faculty expertise. The specific projects that are chosen from year to year will also evolve to reflect the ever-changing characteristics of computer science and information technology. Ideally, each project should build upon basic computer science concepts and help students develop professional skills in the application of technology. Schools should also consider offering project-based courses in conjunction with a local college or university to ensure currency and tap outside expertise.

While some of the project-based courses may be more skills-based, they must still be tied to the "behind-the-scenes" activities of the software and other computer science principles in general. Making such connections enables students to problem solve when software does not perform as anticipated.

Here are some project-based courses that could meet the requirements of a Level 3C course.

Example: Desktop Publishing: This course introduces planning, page layout, and the use of templates to create flyers, documents, brochures, and newsletters. Word processing and graphical editing fluency (Level 2) will help ensure student success. Methods

of distribution of these documents in both written and electronic formats should be included. This will necessitate understanding of Internet concepts and network connectivity (Level 3A).

Example: Technical Communications: The ability to communicate and share ideas should be a core requirement for all high school graduates. This type of project focuses on end-user documentation and researching and presenting technical information to non-technical individuals in oral, written, and multimedia form. Fluency with word processing and presentation software and an understanding of computer science and technology (Level 3A) is required.

Example: Multimedia: The use of multimedia has increased steadily at the user level, fueled by more efficient hardware and the availability of digital cameras and digital audio equipment. However, multimedia is often abused when incorporated into programs, webpages, and presentations. This project will provide instruction in the use of digital audio and video equipment and related editing software. A major focus will be deploying multimedia in a responsible fashion. Basic software skills (Level 2) and an understanding of multimedia concepts (Level 3A) are required.

Example: Graphics: This class explores bitmap and vector-based graphics. The discussion includes benefits and limitations of each type of software and hands-on experience with both. CAD, CAM, and 3-D design software should be explored as well as bitmap software for creating and editing graphics. Availability of a digital camera and scanner is required. Responsible deployment of graphics including style and legal issues needs to be investigated. The discussion of vector-based graphics will be facilitated by completion of Level 3A—limits of computers and design for usability.

Example: Game Programming: This course helps students understand the creativity needed to program effectively and reinforces the software development cycle. Students plan, design, code, and test computer games. Basic programming skills and an understanding of media (level 3B) are required.

Example: Computational Modeling: This course explores the computational modeling of complex systems. Using agent-based techniques, locally relevant issues such as the spread of disease, ecosystems, and traffic patterns can be modeled and investigated and efforts to ameliorate negative impacts can be designed and tested virtually. In this course students will come to understand how interactions between individual elements (e.g., people, animals, or cars) and individuals and their environment can give rise to emergent, often unpredictable, patterns. Student project work includes abstracting a real-world issue or scenario, implementing a computational model by specifying the agents, interactions and environment in the model, and using automation to perform multiple runs of the simulation as an experimental testbed. Analysis of the model itself and the data it produces determine if and how the simulated world relates to the real world.

Example: Web Development: At several places in the curriculum students are exposed to Internet concepts and HTML. This course includes Cascading Style Sheets (CSS) and presents a more in-depth view of the design and development issues that need to be considered for a multi-platform international implementation. The standardization of webpage development using the recommendations of the WWW Consortium is one focus issue. Webpage development will include coding HTML and CSS using a text editor and utilizing simple scripts to enhance webpages.

Example: Web Programming: Students who have successfully completed Levels 3A and 3B but do not wish to take an AP course might nevertheless enjoy applying their programming skills to the WWW. To be successful, a solid understanding of Internet concepts, web development issues, and basic programming concepts will be required. Topics in this course can include client-side and server-side scripting languages. Students will need to write scripts and deploy them within webpages or on the web server.

Example: Emerging Technologies: This project can include several distinct topics, and its content is expected to change on a regular basis. Curriculum and materials for this topic would need to be developed from current resources on the web, perhaps in conjunction with local colleges and universities, and with input from the professional sector of the Business Community.

Example: Free and Open Source Software (FOSS) Development: Students who have successfully completed Level 3A may enroll in a course where they can contribute to an ongoing FOSS software project. Here, they might read code written by others, contribute suggestions for new features, identify bugs, write user documentation, and learn to use modern collaborative technologies. Students would actively participate in project discussion threads. Examples of FOSS projects that are accessible to students are identified at http://hfoss.org.

Some other topics (along with their prerequisites) include:

- The computer and animation (Level 3A)
- Networking technologies (Level 3A)
- Programming simulations (e.g., a computer-controlled chemistry experiment) (Levels 3A and 3B)
- Object-oriented design and coding (Level 3B)
- Effective use of computer applications (Levels 1 and 2)

5.3.C.3 *Courses Leading to Industry Certification*

Such a course is primarily geared toward students planning on entering the workforce, continuing their education in a post-secondary technical school, or entering a two-year college Associates of Applied Science program. Students taking this course should have completed Levels 1 and 2, and typically the Level 3A courses.

Industry certification provides a standard that is useful to potential employers in evaluating a candidate who has no prior work experience. Industry certifications are either vendor-neutral or vendor-sponsored. Vendor-sponsored curricula need to be evaluated carefully. While rich in content, some of these courses are structured to emphasize proprietary products rather than general concepts. Students who complete certification courses should be encouraged to take the corresponding exam as proof of acquired knowledge. Here are a few examples of vendor-neutral certification programs.

Example: A+ Certified Technician: The CompTIA A+ certification is the industry standard for computer support technicians. The international, vendor-neutral certification proves competence in areas such as installation, preventative maintenance, networking, security and troubleshooting (http://www.comptia.org/certifications/listed/a.aspx). Two different exams are available: CompTIA A+ Essentials and CompTIA A+ Practical Application. The use of critical thinking skills to problem-solve is necessary to troubleshoot and resolve problems. These skills reinforce and extend the concepts presented in Levels 1, 2, and 3A.

Example: Quick Security+: The field of computer security is one of the fastest-growing disciplines in Information Technology. CompTIA Security+ is an international, vendor-neutral certification that demonstrates competency in network security, threats and vulnerabilities, access control and identity management, cryptography, and more (http://certification.comptia.org/getCertified/certifications/security.aspx). These skills reinforce and extend the concepts presented in Levels 1, 2, and 3A.

Example: Certified Internet Webmaster (CIW): CIW's core curriculum focuses on the foundational standards of the web, including web design, web development and web security. CIW certifications verify that certified individuals have the skills to succeed in a technology-driven world (http://ciwcertified.com/About_CIW/index.php). CIW curriculum is state-endorsed in various areas of the country (http://ciwcertified.com/About_CIW/Why_CIW/highschools.

php). The CIW Web Foundations exam requires competency in Internet business, web design, and networking fundamentals. Many of these concepts are introduced in Levels 1, 2, and 3A.

Find more detailed information about these and other certification programs, both vendor-specific and vendor-neutral, by searching the Web.

6. Implementation Challenges

We understand that many obstacles lie in the way of arriving at an ideal model of K–12 computer science education for all students. How will room be found in the jam-packed curriculum? How will qualified teachers be recruited, trained, and credentialed? In the world of standards-centric evaluation of schools, should computer science support existing standards, or should new ones be designed for computer science? These and other questions and challenges are significant, but so are the benefits—to students and to society—of computer science becoming as much a part of a high-quality education as other core disciplines.

Teaching any subject effectively depends on the existence of sound learning standards for students, explicit teacher certification standards; appropriate teacher training programs; effective curricular materials; and a core of teachers who are willing, able, and empowered to deliver the curriculum. K–12 computer science education faces unique challenges along all of these lines.

The challenge of improving computer science education is significant and will require attention and interventions from multiple institutions. Professional organizations in computer science can make an important contribution. CSTA, for example, is a professional organization that supports and promotes the teaching of computer science and other computing disciplines. CSTA provides a large number of programs that include the development and dissemination of learning resources, the provision of professional development, and advocacy for state and federal level policies to improve computer science education. Other organizations such as ACM, the IEEE Computer Society, institutions of higher education, and national and local teacher organizations can also work to address these issues in K–12 computer science education. Industry is also deeply affected by pipeline issues and the scarcity of workers who have the skills to support and build the technology tools of the future. It is therefore in their best interest to contribute significantly to improving access to the quality of computer science courses at the K–12 level.

For schools to widely implement these standards, work is needed in three important areas: *teacher preparation, state-level content standards, and curriculum materials development*. In addition, persons in leadership positions must acknowledge the importance of computer science education for the future of our society. States and accrediting organizations should make this a factor in their overall school accreditation process. Some states have begun to establish computer science content standards, define models for teacher certification, provide in-service training in computer science, and experiment with developing new curricular materials. However, a much wider effort and commitment are now required.

Recently, efforts have increased to develop national and state content standards for computer science. Curriculum standards serve to define the skills and knowledge of the discipline to be acquired by every student. Content standards for computer science education within states must be developed and adopted in a way that parallels what has occurred in disciplines such as science, mathematics, and language arts. Curriculum content that is aligned with these standards can then be developed for the classroom.

In the design of state standards, it is important to ensure the distinction between the teaching of IT skills and the teaching of computer science itself. That is, computer science must be viewed as a distinct subject area and technology should be viewed as a tool that cuts across all subject areas. Existing technology

standards, where present, should not be substituted for computer science standards. (For a comprehensive discussion of the ways in which states have failed to incorporate computer science standards into state standards in this way, see *Running on Empty: The Failure to Teach K–12 Computer Science in the Digital Age* at http://csta.acm.org/Communications/sub/Documents.html.

7. Call to Action

Computer science is a mainstream discipline that can no longer be ignored by public schools in the 21st century. The learning standards detailed in this document provide a basis by which states, schools of education, and individual school districts can begin to implement a coherent computer science curriculum that is available to all students.

Much work needs to be done to translate these standards into teaching and laboratory materials that are pedagogically robust and culturally meaningful for all students. We hope state and federal departments of education, corporations, foundations, and other external stakeholders will support this work by providing appropriate incentives that will enable such a massive curriculum development effort to succeed.

Notes

8. Activities

In these activities, we illustrate the viability of this curriculum model by providing example activities for courses and modules that are now being taught in various schools throughout the world. The structure of these activities is explained below:

ACTIVITY: NAME OF THE ACTIVITY

Time:	Number of in-class hours to complete the activity
Description:	Brief description of the subject and goals of the activity.
Level:	1, 2, or 3, as defined in this report (see Section 4.1)
Topics:	The topics at this level that are covered by this activity (see the topic lists in Sections 5.1, 5.2, and 5.3 of this report)
Prior Knowledge:	What students should know before beginning this activity
Planning Notes:	Suggestions to teachers for preparing this activity
Teaching/Learning Strategies:	Organization of the in-class presentation and the particular student tasks
Assessment and Evaluation:	Formative and summative assessments of in-class and laboratory work
Accommodations:	Additional supporting materials (e.g., scaffolding labs, example programs, challenging problems)
Resources:	Links to the source of this activity, as well as other related activities

A.1 Sample Activities for Level 1

ACTIVITY: A MYSTERY PLAY

Time:	8 hours
Description:	Students learn and act out a short mystery play. Other students use logic to solve the mystery.
Level:	1
Topics:	Understand the fundamental ideas of logic and its use for solving real-world problems
Prior Knowledge:	Elements of logic (statements, truth and falsity), reading and speaking skills.

Planning Notes:

- Students will need time to learn their parts and rehearse the play in advance.

Teaching/Learning Strategies:

- The play is about 20 minutes long.
- The setting is a classroom, so no special props or scenery are needed.

Assessment and Evaluation:

- Students discuss the mystery and the reasoning they used to solve the mystery.

Accommodations:

Students receive copies of the play, which is 3 scenes and 4 pages long.

ACTIVITY: BATTLESHIPS

Time: 4 hours

Description: Computers are often required to find information in large collections of data. They need to develop quick and efficient ways of doing this. This activity demonstrates three different search methods—linear search, binary search, and hashing—using numbered cards and the game of battleships as vehicles.

Level: 1 (Grades 3–5)

Topics: Basic understanding of a search algorithm

Prior Knowledge: Mathematics; greater, less, and equal relationships, geometry (coordinates)

Planning Notes: Finding information efficiently—linear search, binary search, hashing

Teaching/Learning Strategies:

- 15 children have cards with different numbers on them, arranged randomly and hidden from one of the children who tries to guess who holds a mystery number. The game is repeated after the 15 numbers are rearranged in order.
- Children are grouped in pairs, and each pair is given two battleship game cards. The game is played using a simple hashing technique to locate the column of a ship on the card.

Assessment and Evaluation:

- Discussions should explore the scores children achieved in each game.
- Discussions should also explore the advantages and disadvantages of each search strategy.

Accommodations:

Each child will need a battleships game card (copied from masters)

Resources:

See http://csunplugged.org/ to learn more about this activity.

ACTIVITY: BEAT THE CLOCK

Time: 4 hours

Description: There is a limit to how fast computers can solve problems. One way to speed them up is to use several computers to solve different parts of a problem. This activity uses sorting networks to do several comparisons at the same time.

Level: 1 (Grades K–2)

Topics: Understanding how to arrange (sort) information into useful order

Prior Knowledge: Grade 2 mathematics; greater than, less than

Planning Notes:

Some tasks can be done faster using fewer steps, while others can be done faster using parallel computation. Sorting networks is a good example of the latter.

Teaching/Learning Strategies:

- Six students hold one number each and arrange themselves on the left-hand side of the court. They move forward to the next circle in the network and wait for someone else to arrive.
- The circle is a decision point from which the student with the smaller number goes left and the larger number goes right.
- At the end, the numbers are sorted.

Assessment and Evaluation:

- Students successfully sort the numbers using the given network.
- They also discuss the use of other networks for sorting.

Accommodations:

This is an outdoor group activity. Chalk, two sets of six cards with numbers on them, and a stop watch are needed. A master is used to draw a sorting network on the sidewalk.

Resources:

See http://csunplugged.org/ to learn more about this activity.

ACTIVITY: COLOR BY NUMBERS

Time:	3 hours
Description:	The computer stores drawings, photographs, text, and other pictures using only numbers. This activity demonstrates how that is done.
Level:	1 (Grades K–2)
Topics:	Using 0s and 1s to represent information
Prior Knowledge:	Grade 2 geometry (exploring shapes, counting, graphing)

Planning Notes:

- Motivational discussion questions include, "What does a fax machine do?"
- "In what situations would a computer want to store pictures?"
- "How do computers store pictures when they can only use numbers?"

Teaching/Learning Strategies:

- A 5x6 rectangular grid is used as a basis for representing different images (such as letters) by coloring in some of the squares (pixels).
- Coding of the image is done by scanning the sequences of 1s (shaded squares) and 0s (non-shaded squares) in each row of the grid and recording the length of each sequence.

Assessment and Evaluation:

Worksheet activities.

Accommodations:

No computers are required; students use two worksheet activities, called "Kid fax" and "Make your own picture"

Resources:

See http://csunplugged.org/ to learn more about this activity.

ACTIVITY: DANCING CAT

Time:	60 minutes
Description:	Students construct a Scratch program to make a sprite dance.
Level:	1
Topics:	Recognize that software is created to control computer operations in a sequential manner.
Prior Knowledge:	Students should have a basic familiarity interacting with a computer and its input devices.

Planning Notes:

In preparing for this activity, teachers should:

- Decide how he/she would like the cat sprite to "dance." A sample dancing cat program is explained in the Getting Started Guide: http://scratched.media.mit.edu/resources/getting-started-guide.
- Decide what concepts he/she would like to emphasize in his/her modeling of the activity. For example, if students are fairly new to programming and Scratch, the teacher can present how to drag and click blocks to make the cat sprite perform actions such as moving 10 steps.

Teaching/Learning Strategies:

This activity involves the following steps:

- The teacher models the Dancing Cat activity for students. For example, the teacher can:
  - Present how Scratch looks when it first opens, with the Blocks Palette on the left, the Scripts Area, and the Stage with the cat sprite.
  - Drag a Move block from the Blocks Palette to the Scripts Area.
  - Click on the Move block in the Scripts Area. Point out how the cat sprite moves 10 steps on the Stage.
  - Drag a Play Drum block from the Sound category and connect it to the Move block to create a stack of blocks or a script. Point out the white highlight that appears as you connect the two blocks. When a block is being dragged in the Scripts Area, the white highlight indicates where that block can make a valid connection.
  - Click anywhere on the stack to run the script. Point out how the cat sprite moves 10 steps and then plays a drum sound. Scratch runs a script starting from the top of a stack.
  - Build the rest of the dance script with the Move and Play Drum blocks. To mimic the back and forth movement of dancing, enter -10 for the second Move block. After adding each new block, click on the stack and point out the new actions that the cat sprite performs on the stage.
  - Drag a Forever block from the Control category and connect it to the top of the stack, enclosing all the blocks.
  - Click on the stack again and point out how the sequence of actions repeat over and over again.
  - Drag the When Green Flag Clicked block from the Control category and connect it to the top of the stack.
  - Click on the Green Flag above the Stage. Point out how clicking on the Green Flag now runs the script.
- Students build their own Dancing Cat projects. The teacher should encourage them to experiment, finding new ways to express dancing or extending their program such as creating their own sprite.
- If there is time, students walk around and see each other's work. Students may also do a show and tell, explaining their projects to their peers.
- After students complete their projects, the teacher facilitates a discussion around some of the ways students programmed their sprite to dance.

Assessment and Evaluation:

- If there is time for students to walk around or do a show and tell, students can describe their projects and their process in creating their scripts. They can also evaluate the scripts of their peers.
- In the closing discussion, students can articulate what they learned in creating their Scratch program.

Accommodations:

While this activity can be carried out without any supplemental materials, the teacher may want to have the Getting Started Guide available for students to support them in the activity.

Resources:

- Getting Started Guide: http://scratched.media.mit.edu/resources/getting-started-guide
- ScratchEd: http://scratched.media.mit.edu/

ACTIVITY: ICE CREAM STAND

Time: 4 hours

Description: A graph is used to represent the map of a city. An ice cream company wants to build ice cream stands at different intersections, so that it is easy for people to get to them but not too many stands have to be built.

Level: 1 (Grades 6–9)

Topics: Understand the graph as a tool for representing problem states and solutions

Prior Knowledge: Elementary map reading

Planning Notes:

- Pass out copies of a map of a town, where lines represent streets and circles represent intersections.

Teaching/Learning Strategies:

- Children must determine the smallest number of stands to build so that no person has to walk to more than one intersection to buy ice cream.

Assessment and Evaluation:

- Children discuss different strategies for placing the stands, and they evaluate each other's solutions.

Accommodations:

Copies of different city maps need to be handed out.

ACTIVITY: THE ORANGE GAME

Time: 4 hours

Description: This activity uses a simple game with oranges to illustrate Internet traffic management (routing) and deadlocks.

Level: 1 (Grades 3–6)

Topics: Simple algorithms for network routing

Prior Knowledge: Math; logic and reasoning

Planning Notes: This is a group activity, requiring five or more children sitting in a circle and having different letters on their shirts. There are two oranges for each child's letter except one, for which there is only one orange.

Teaching/Learning Strategies:

- Every child is given an orange in each hand (except that one child has one orange) randomly.
- Oranges are passed between children until everyone has two oranges with his/her own letter.
- Only an empty hand can receive an orange, and only from an adjacent hand.

Assessment and Evaluation:

- Children should learn that holding onto one's own orange as soon as it is received may prevent the whole group from achieving its goal.

Accommodations:

- A bag of oranges

Resources:

See http://csunplugged.org/ to learn more about this activity.

ACTIVITY: YOU CAN SAY THAT AGAIN

Time: 4 hours

Description: Text can be compressed by taking advantage of patterns in words and linking repeating patterns to each other without rewriting them. For instance, "pitter patter" can be encoded by replacing the last instance of "tter" by a link to the first instance.

Level: 1 (Grades 3–6)

Topics: Develop a simple understanding of an algorithm

Prior Knowledge: English, recognizing patterns in words, copying written text; basic familiarity with computers

Planning Notes: Images and text containing millions of pieces of information are transmitted on the Internet every day. To save time and space, they are compressed into ZIP or GIF format before they are transmitted.

Teaching/Learning Strategies:

- Students successfully encode and decode text, using worksheets.
- They also discuss the kinds of texts and images that compress best/worst using this algorithm.

Assessment and Evaluation:

- Students' completed worksheets are evaluated.

Accommodations:

Four different worksheets are used to facilitate this activity; a transparency is used to present the compression algorithm.

Resources:

See http://csunplugged.org/ to learn more about this activity.

A.2 Sample Activities for Level 2

ACTIVITY: CONNECTIONS INSIDE AND OUT

Time: 3 hours and 40 minutes

Description: Students view the video The Journey Inside the Computer (from Intel Corporation (http://educate.intel.com/en/thejourneyinside/) and examine the individual internal components of the computer. Using resources available to them, students discover the importance of each component and its impact on the computer's operations. The activity culminates with a series of problems that students must solve using the new knowledge. Finally, students use this information to suggest an alternative placement of computers within the school environment that makes a positive impact on the school community and demonstrates wise use of resources.

Level: 2

Topics: Students will gain a conceptual understanding of the principles of computer organization and the major components (input, output, memory, storage, processing, software, operating systems).

Students will gain a conceptual understanding of the basic components of computer networks (servers, file protection, queues, routing protocols for connection, communication, spoolers and queues, shared resources, and fault-tolerance).

Prior Knowledge: the differences between hardware and software:

- ability to record findings from observation,
- familiarity with the operating system they are using and the term network, and
- familiarity with internal components and their uses.

Planning Notes:

- Request permission for students to visit certain areas of the school during class time—plan this as an in-school field trip.
- Think of visiting a music midi lab, communication lab, front office, and any specialized resources specific to your local environment.
- Check with the site administrator if you are not sure of network type(s) available in the school.
- Prepare checklist of terms for student use during video.
- Arrange to have a computer site administrator from the school or board office or a computer technician speak to the class about networks and operating systems
- Have a school map available for students to take on tour and an overhead of the map for review.
- Check for materials from The Journey Inside the Computer kit available from Intel (Intel Corporation. The Journey Inside. Part of The Journey Inside Education kit.)

Teaching/Learning Strategies:

- Show The Journey Inside the Computer video, Unit 4 on Microprocessors, then Unit 6 on Networking, with the purpose of reviewing computer components and extending student knowledge of networks and operating systems.
- Take up terms sheet and have students complete definitions for words they are unfamiliar with (teachers may introduce students to the online dictionary at www.dictionary.com).

- Share information on networks with students.
- Indicate type(s) of networks currently used in the school environment.
- Share information on operating systems with students.
- Deliver short test on networks and operating systems.
- Provide each student with a map of the school and explain tour route and any special routines required for secure areas.
- Give students a simple key for marking on map (e.g., C = stand alone computer, L = lab, SL = specialized lab, S = server room, P = printer resource).
- Return to the classroom and review the map on an overhead with input from students.
- Encourage a discussion of how improvements that have been made in network and operating systems make a difference in a computer community such as a school.
- Ask them to reflect on why they think the computer resources have been placed in the school the way they are.
- Ask students to prepare a written brief of changes they would like to see in the school computer environment.
- Direct students to include positive effects their suggestions have on the school environment and incorporate their knowledge of networks.
- Facilitate student pair/square and share of suggestions.

Assessment/Evaluation Techniques:

- A formative assessment in use of the review terms sheet, and
- An evaluation of test on networks and operating systems.

Accommodations:

- Give an oral test if appropriate.
- Provide students with physical disabilities assistance if required.
- Assist students with special needs with terms sheet.

ACTIVITY: CULTURALLY SITUATED DESIGN TOOLS—WEAVING

Time: 4 hours

Description: In this lesson, students learn how computers can be used as a tool for visualizing data, modeling and design, and art in the context of culturally situated design tools. Connections between the design of the tools and mathematics will be explored.

Level: 2

Topics: Interact with content-specific models and simulations (e.g., ecosystems, epidemics, molecular dynamics) to support learning and research. Make the connection between elements of mathematics and computer science, including binary numbers, logic, sets and functions. Collaboratively design, develop, publish, and present products (e.g., video, podcasts, wikis, etc.) using technology resources that demonstrate and communicate curriculum concepts.

Prior Knowledge: Understanding of Cartesian coordinate system.

Planning Notes:

- Ensure that the Culturally Situated Design Tools website (csdt.rpi.edu) is available to all students
- The bead loom tutorial is online. You can adapt the Pacific Northwest Basket Weaver and the Navajo Rug Weaver tool from the bead loom tutorial and provide printed copies.
- Create rubric for project and provide it to students in advance
- Review Cartesian coordinate system

Teaching/Learning Strategies:

- Post the possible design tools:
  - Virtual Bead Loom
  - Pacific Northwest Basket Weaver
  - Navajo Rug Weaver
- Display the first page of each tool in order to give students an idea of what each does. (http://csdt.rpi.edu)
  - Students divide into groups to work on the tool of their choice. Group sizes will depend on the size of the class. You may need to have more than one group per tool.
- Each member of the group should go through the entire cultural background section individually.
  - Answer any questions posed in the section in their journal.
  - Look for and write down the mathematical connections.
- All group members discuss the section.
  - Resolve answers to questions and mathematical connections.
- Each member of the group completes the tutorial.
  - Students should go through the tutorial at their own pace, but discuss with other members as questions arise.
  - Encourage students to record in their journal points that they want to remember.
- Groups create designs using the design tool software.
  - Each person should choose one of the goal pictures for practice and discuss any issues with the other group members.
  - Groups decide whether they want to create one design as a group or have multiple designs for their presentation.
  - Groups work on design(s)—these should be their own creations rather than a mimic of one of the preloaded designs.

- Edit designs with Photoshop Express.
  - Have students watch the online tutorial and create an account.
  - Edit the design.
- Prepare presentations to include:
  - Culture
  - Math connections
  - Demo of software
  - Display of designs
- Groups deliver presentations.

Assessment/Evaluation Techniques:

- Students are assessed on their projects, including design, description of culture, math connections, and demo. Students should also be assessed on their work as a team.

Accommodations:

- Use extensive visual aids and demonstrations to assist students as needed.
- Provide appropriate adaptive devices or implementation accommodations for identified students.
- Construct student groups to enable assistance where necessary

Resources:

- Culturally Situated Design Tools: http://csdt.rpi.edu/
  (site and adaptations of tutorials courtesy of Ron Eglash)
  - Virtual Bead Loom Tutorial
  - Pacific Northwest Basket Weaver Tutorial
  - Navajo Rug Weaver Tutorial
  - Culturally Situated Design Tools Project Sample Rubric
- Photoshop Express: http://photoshoponline.com/

ACTIVITY: COMPARE OPEN SOURCE PRODUCTIVITY SOFTWARE WITH COMMERCIAL SOFTWARE

Time: 4 hours

Description: Students develop an understanding of open source productivity software by comparing it with its commercial counterparts. Various features of productivity software will be explored. Students have the opportunity to compare and analyze the results of their findings.

Level: 2

Topics: The comparison of Open Source productivity software with its commercial counterparts.

Prior Knowledge: Working knowledge of commercial productivity software.

Planning Notes:

- Review the purpose of and features of various types of productivity software: word processing, spreadsheets, presentation
- Have commercial productivity software installed, such as Microsoft Office.
- Have open source productivity software installed, such as Open Office.
- Visit openoffice.org or appropriate URL for your open source software and review different kinds of open source productivity software available.

Teaching/Learning Strategies:

- Select a set of tasks to perform (examples: create a flyer in word processing software, create a table and a chart in spreadsheet software, create a slide show in presentation software).
- Split the class in teams of two.
- In every pair, have one student use commercial products, and the other student use open source products to complete an assigned task.
- Once completed, have the students compare the results and identify similarities and differences in working with the software and in the final output.
- Each pair of students is to create a report stating their findings. This report should cover the following categories: task(s) completed, types of software used, features used in that software, similarities/differences. The report should conclude with a statement about which software the team preferred and why.
- Once reports are submitted and/or presented to class, open discussion may follow about relative benefits and drawbacks of using open source products vs. commercial products. The discussion may include but is not limited to initial costs, licensing costs, and support costs of both types of software.

Assessment/Evaluation Techniques:

- Report on similarities and differences between commercial and open source software.
- Participation in class discussion.

Accommodations:

- Step-by-step instructions on how to complete a given task in a word processor, spreadsheet, and presentation software.
- User Manual or Help on how to use productivity software.

ACTIVITY: NUMBER SYSTEMS

Time: 4 hours

Description: Students develop an understanding of the relationship between the binary number system and computer logic. Also, students learn how to convert Base 10 numbers into binary and vice versa. Character representation of binary codes is explored. Students have the opportunity to experiment in writing their own message and decoding.

Level: 2

Topics: The connection between elements of mathematics and computer science, including binary numbers, logic, sets and functions.

Prior Knowledge: Understanding of the decimal number system and place value

Planning Notes:

- Review how programming software handles character representations.
- Have eight pennies for each pair of students and either a handout and/or overhead of bit information
- Review binary and base 10 conversions.
- Prepare coded messages for the students to decipher.
- Have copies of ASCII code available (both standard and extended).

Teaching/Learning Strategies:

- Show segment 3 of The Journey Inside video (8 min 25 sec—Intel Corporation. The Journey Inside. Part of The Journey Inside Education kit) or any other video that shows how computers turn pictures and colors into codes. Students gain an understanding of how information is communicated through the use of codes.
- Hand each pair of students eight pennies and work through the questions on bit information. Ask students what pattern they can see forming in the right column (numbers double).
- Students are challenged to count as high as they can on one hand and told the answer is greater than 10. While students ponder the challenge, teachers demonstrate, with the aid of a simple series circuit, the binary logic states of ONE and ZERO (TRUE and FALSE, HIGH and LOW) by equating them to series circuit lamp ON and OFF condition.
- Binary numbers are introduced by initiating finger counting on one hand—no fingers up is zero, thumb up is a one, index finger up is two, middle finger up is a four, ring finger is eight, and pinkie finger represents sixteen. Students demonstrate counting to 31 on one hand.
- This sets the stage for demonstrating how to convert numbers from Base 10 to Base 2 (binary). Work through several examples with students.
- Give students a quiz on binary conversion to assess their grasp of the concept.
- Handout the ASCII conversion information. Since computers cannot think like we do, they need a code to translate our language into data that they can process and then convert that data back into recognizable language.
- Students complete conversion exercises.

Assessment/Evaluation Techniques:

- Formative assessment of quiz at the end of the binary conversion exercise to prompt students on progress and show changes required for success of conversion application.
- Summative assessment of conversion exercises.

Accommodations:

- Use extensive visual aids and demonstrations to assist students as needed.
- Provide an enlarged copy of conversion methodology in classroom as well as ASCII character chart.
- Use a variety of teaching styles to accommodate learning styles.
- Provide appropriate adaptive devices or implementation accommodations for identified students.

ACTIVITY: PASS-IT-ON

Time:	90 minutes
Description:	In this activity, students collaboratively and incrementally construct projects using Scratch by passing the projects from student to student.
Level:	2
Topics:	Collaborate with peers, experts, and others using collaborative practices such as pair programming, working in project teams, and participating in group active learning activities (e.g., CS unplugged and KLAs). Design, develop, publish, and present products (e.g., webpages, mobile applications, animation) using technology resources that demonstrate and communicate curriculum concepts.
Prior Knowledge:	Students should have at least a basic familiarity with Scratch and its mechanism of snapping blocks together to specify program instructions.

Planning Notes:

In preparing for this activity, teachers should:

- Select a theme for the pass-it-on project. Some themes that we have tried before and have been popular include pass-it-on stories and pass-it-on dance parties. The content of pass-it-on projects can also be connected to various curricular areas.
- Decide which Scratch features and computational concepts will be demonstrated in the opening introduction.

Teaching/Learning Strategies:

This activity involves the following steps:

- The teacher models the activity by starting a pass-it-on project. For example, the teacher might demonstrate how to start a dance party project, by adding music, a background, and a party-goer. The teacher explains the pass-it-on process and, as an example, makes (or solicits) two or three suggestions for elements that could subsequently be added to the model project (e.g., additional party-goers, more costumes).
- The students (either individually or in pairs) each use a computer to start their pass-it-on projects. They have 15 minutes to work on their projects.
- After 15 minutes, the students rotate to a new computer and continue building the project they find at the new computer. They have 15 minutes to work on their projects.
- After 15 minutes, the students rotate a final time and work on a third project. They have 15 minutes to work on their projects.
- At the end of this final 15 minutes, the students return to their original computer to see how the project they started has evolved.
- Depending on the number of projects, students can walk around to view all (or some subset) of the other pass-it-on projects.
- The teacher facilitates a discussion about the concepts and features students learned as they worked on the projects and looked at others' code.

Assessment and Evaluation:

- The closing discussion: The discussion can be used to make explicit the different concepts and features students learned and the challenges they experienced.
- The pass-it-on Scratch projects: The projects can be evaluated for process (e.g., the nature of the collaborative activity, how students supported each others' learning) and product (e.g., the feature and concepts that were included in the project, the ways in which the theme was creatively appropriated). This evaluation can include self-evaluation, peer-evaluation, and instructor-evaluation.

Accommodations:

Although this activity can be completed without supplemental materials, the concepts and features demonstrated in the teacher's initial modeling can be supported by making handouts available that suggest things to try. For example, the following handouts could be accessible nearby as students work on their creations:

- Scratch cards: A set of 12 code excerpts. http://scratched.media.mit.edu/resources/scratch-cards
- Monkey business: A one-page suggestion of introductory blocks to experiment with. http://scratched.media.mit.edu/resources/monkey-business

Resources:

- Video, documenting the "Pass-it-on story" activity, as done with a group of teenage girls. http://scratched.media.mit.edu/stories/csed-week-day-4-wise-dance-party
- ScratchEd online community. http://scratched.media.mit.edu/

ACTIVITY: SETTING UP A COMPUTER

Time: 2 hours and 30 minutes

Description: Students set up a computer including installing available software and an operating system. Students connect, configure, and test all peripherals. Finally, students troubleshoot any problems that arise. All students set up a PC.

Level: 2

Topics: Students will gain a conceptual understanding of the principles of computer organization and the major components (i.e., input, output, memory, storage, processing, software, operating systems).

Prior Knowledge: Components of a computer system, correct terminology

Planning Notes:

- Prepare available samples of micro-controllers and PCs of various types.
- Determine the most effective use of existing hardware within the recommended time allotment (e.g., two to three students per computer).
- Open an older discarded hard drive for demonstration purposes.
- If resources are limited, a single system may be set up several times to accommodate all students.
- This activity is done with stand-alone machines to not interrupt a networked environment.
- The teacher should review the procedures in the attached appendices. This activity assumes that the computer system hard drive has been configured prior to the installation of the operating system.
- The actual system installation can be performed as a class "walk through." The teacher can modify the process to have the individual groups perform the set-up task.
- The teacher should review the disk partitioning, formatting, scandisk operations, and information available in the Help files of the operating system (see Resources).
- Inventory the operating system CD-ROM and software key.
- Ensure all software is available for the full installation including operating systems, device drivers, and application software.

Teaching/Learning Strategies:

- Teachers and students review safety with static electricity and the importance of keeping contacts clean as they apply to components. Review the safety considerations when setting up a desktop computer (grounded plugs, using power bars, dangling cords, eliminating the danger of static electricity, and unplugging power supply before opening a PC, etc.).
- The teacher explains how hard drives work so that students can understand the utility functions they are required to complete by the end of the activity.
- Students use the equipment they require to complete the task, including the monitor, CPU, keyboard, mouse, and a printer, if available. The teacher explains any special considerations they need to know (e.g., positioning of computers for plugs in the room). Students use this information to create a checklist for the activity.
- Depending on the resources available, divide students into the appropriate number of groups. Students connect all the parts of their computer system. Circulate to help with troubleshooting and use questioning techniques to assist with problem solving.
- Once all components are connected, students load the operating system software. Students complete their personal checklist.
- All groups must then test their software to ensure their system is working and that all peripherals connected are functioning properly.

Assessment/Evaluation Techniques:

- A formative assessment through student discussion and observation, encouraging students to assess their thinking for successful completion of task.
- Assess student-created checklists. Provide students with written/oral feedback, to assist their success in upcoming related activities.

Accommodations:

- Provide step-by-step instructions.
- Provide a glossary of terms.
- Provide visuals of different computer types.

A.3 Sample Activities for Level 3

ACTIVITY: CAREERS IN COMPUTER ENGINEERING

Time: 3 hours and 45 minutes

Description: A guest speaker is invited to share information about his/her career with the students. Students expand on their computer industry knowledge. Students look at degrees and certifications available and opportunities they have at the high school level and beyond to move them toward careers in the computer industry.

Level: 3A, 3B (could also be used for Level 2 with some modification)

Topic: Students will gain a conceptual understanding of the identification of different careers in computing and their connection with the subjects studied in this course (e.g., information technology specialist, webpage designer, systems analyst, programmer, CIO).

Prior Knowledge: Word-processing skills

Planning Notes:

- Guest speakers may include the school system administrator, district technician, or someone from the local community.
- Collect information from a local university or community college, including school course calendars and college/university catalogues.
- Gather copies of recent computer trade magazines.
- Arrange ahead of time for a student to introduce guest speakers and another student to thank them.
- Collect newspaper advertisements for jobs in the computer industry.
- Distribute a sample certification worksheet

Teaching/Learning Strategies:

- Teachers introduce the expectations of the activity.
- Teachers review with students (ahead of time) questioning techniques for the guest speaker.
- One student may introduce the guest speaker. Students take brief notes in order to ask relevant and interesting questions.
- Discuss the speaker information with the students, after which they write their personal views on the information.
- Students look through trade magazines to see advances in the computer industry. Each student picks one article from a magazine to summarize or review using a word processor.
- Finally, students look at opportunities for different computer designations ranging from MCSE (Microsoft Certified Engineer) to computer engineering at the university level. Students use newspaper advertisements to explore what skills and designations are requested by potential employers.
- Students retrieve the certification chart file (either electronically or via handout) and, using designations discovered in the advertisement exercise above, they complete the chart.
- Students create a plan on how to pursue a computer career, beginning with the completion of this course, and save the information in their portfolio (long-term goal).

Assessment and Evaluation:

- Provide feedback on completion and comprehension of tasks given.
- Evaluate the article review using a rubric you have created.

Accommodations:

- Allow flexible timelines for due date of report.
- Use career center videos if available.
- Invite the Student Services resource personnel into the classroom.
- Videotape the guest speaker's presentation to allow students an opportunity to watch it again.

ACTIVITY: CULTURALLY SITUATED DESIGN TOOLS—CORNROW CURVES

Time: 3 hours

Description: This lesson serves as a reinforcement of the problem-solving process and connections between mathematics and computation within the context of a culturally situated design tool.

Level: 3A, 3B

Topics: Explain how sequence, selection, iteration, and recursion are building blocks of algorithms; Describe how computation shares features with art and music by translating human intention into an artifact; Describe how computing enhances traditional forms and enables new forms of experience, expression, communication, and collaboration.

Prior Knowledge: Understanding of Cartesian coordinate system.

Planning Notes:

- Ensure that csdt.rpi.edu is accessible to all students
- Create rubric for project and provide it to students in advance
- Review Cartesian coordinate system

Teaching/Learning Strategies:

- Cultural background of cornrow braiding
  - Students read the cultural background and how to braid sections (csdt.rpi.edu, Cornrow Curves).
- Group discussion on cultural background of cornrow braiding
  - Divide students into groups of 3–4 and ask each group to reflect on one of the following sections:
- African Origins
- Middle Passage
- Civil War to Civil Rights
- Hip Hop
  - Each group shares their response with the rest of the class.
- Cornrow curves design tool tutorial
  - Individual students complete Part I of the tutorial following all instructions and checking their work with their elbow partner.
  - Discuss any issues as a class before proceeding to Part II.
  - Complete Part II of the design tutorial.
  - Stress mathematics and structured inquiry.
- Cornrow curves project
  - Students create their own design.
  - Describe each step of the problem-solving process used.
  - Highlight the mathematical concepts used and where used.
  - Reinforce the strategy of finding a similar problem that has already been solved to help solve the new problem.

- Gallery walk of designs
  - Students share their solutions.

Assessment/Evaluation Techniques:

- Students are assessed on their projects, including design, description of process used, and description of mathematical concepts used.

Accommodations:

- Use extensive visual aids and demonstrations to assist students as needed.
- Provide appropriate adaptive devices or implementation accommodations for identified students.
- Construct student groups to enable assistance where necessary

Resources:

- Culturally Situated Design Tools Cornrow Curves—csdt.rpi.edu (courtesy of Ron Eglash)

ACTIVITY: NEW SOLUTIONS FOR OLD PROBLEMS

Time:	5 hours
Description:	Students examine problems that can be solved using more than one algorithm (e.g., determining the factorial value of a number). Using brainstorming or other group problem-solving techniques, students develop alternative algorithms using recursive and non-recursive techniques. Students identify the components of a recursive algorithm and develop criteria for recognizing when a recursive algorithm may be applied.
Level:	3A, 3B
Topics:	Fundamental ideas about the process of program design, and problem solving, including style, abstraction, and initial discussions of correctness and efficiency as part of the software design process. Simple data structures and their uses.
Prior Knowledge :	Use of problem-solving models, the ability to develop appropriate algorithms to solve problems, and the ability to write pseudocode.

Planning Notes:

- Review the nature of recursion.
- Gather examples of problems that can be solved using more than one method, including recursion, and determine which problems may be solved using a recursive algorithm.

Teaching/Learning Strategies:

- Divide the class into groups of two or three students.
- Review the brainstorming problem-solving technique.
- Present a problem that can be solved using a familiar but complex algorithm and may also be solved using a less familiar but simpler algorithm (e.g., determining the quotient and remainder of the division of two integers).
- Students, in their groups, develop more than one algorithm for the solution.
- The teacher facilitates a class discussion to develop criteria for the evaluation of algorithms, including the efficiency of the solution and the complexity of the required coding. Both processing and user interface efficiencies are considered.

- Groups evaluate the algorithms using the developed criteria and share their algorithms and evaluations with the class.
- The teacher introduces the recursive method of problem solving and illustrates a recursive algorithm for the solution to a different problem (e.g., calculating the factorial value of a number).
- Groups develop a recursive algorithm to the initial problem and evaluate its efficiency.
- The teacher facilitates a class discussion to establish criteria for determining if a recursive algorithm is an appropriate solution and identifies additional problems that may be solved using recursion.
- Working in groups, students develop recursive and non-recursive algorithms for additional, assigned problems.

Assessment and Evaluation:

- A formative assessment of the assigned in-class work in the form of roving conferences, and
- A summative assessment in which students complete an assignment requiring the development of both a recursive and a non-recursive algorithm.

Accommodations:

- Provide print copies of examples of algorithms using recursive and non-recursive methods, including graphic illustrations, and use models to illustrate the algorithms.

ACTIVITY: PLANNING A SOLUTION

Time:	6 hours
Description:	Students work in groups to analyze complex problems (e.g., Towers of Hanoi) and to develop appropriate algorithms using recursive and non-recursive techniques. Students create pseudocode and design charts to assist them in planning a solution and assess these representations of code as problem-solving tools.
Level:	3A, 3B
Topics:	Fundamental ideas about the process of program design, and problem solving, including style, abstraction, and initial discussions of correctness and efficiency as part of the software design process.
Prior Knowledge:	Students can apply the steps in the software design life cycle; use pseudocode, diagrams, and charts to summarize program design; and develop appropriate algorithms to solve problems.

Planning Notes:

- Review top-down problem solving.
- Select a problem to use in developing a model solution and prepare the appropriate models.

Teaching and Learning Strategies:

- The class is divided into groups of two or three students and each group is assigned a problem.
- Groups investigate the problem, using a variety of problem-solving techniques to analyze it.
- Each group uses brainstorming or other group problem-solving techniques to develop an algorithm for the solution to the problem. In a class discussion, groups present and share their algorithms.
- Students compare the effectiveness and efficiency of the algorithms presented and then the groups refine their algorithms.
- Each group develops a flow chart, structure chart, and/or pseudocode to represent the application of the algorithm. The teacher conferences with each group to discuss and assess the solution design.

Assessment and Evaluation:

- A formative peer assessment of the presented algorithms.
- A formative assessment of the design for the solution to the problem.

Accommodations:

- Provide print sample algorithms similar to the one studied.
- Use graphical models to illustrate the problem.
- Selectively pair/group students to assist problem solving.
- Provide problems of varying complexity to provide an appropriate challenge.

ACTIVITY: ROLE PLAYING HELPER FUNCTIONS/RECURSION

Time:	1 hour
Description:	Students role play various objects of simple programs to understand parameter passing and recursive calls
Level:	3B, 3C.1
Topics:	Methods (functions) and parameters, recursion
Prior Knowledge:	Compile and run simple programs; write code using parameters.

Planning Notes:

- Prepare or obtain from resources scripts for role playing objects in a small program with several nested (and usually also recursive) calls.
- Gather colored markers and poster board as needed.

Teaching/Learning Strategies:

- Review the concepts of constructors, parameters, and calling helper methods.
- Students read code for the program to be used for the role play.
- Select a student to role play the main function. If desired, give student a large name tag to wear. Select another student to be the code monitor whose job is to keep a record of the current line of code being executed.
- Assist class as they act out the script, each time an object is constructed the student calling the constructor function picks a classmate to play the role of the object; if using name tags, be sure to give each object-player a name tag. Using different sized, shaped, or colored tags for different classes is helpful.
- Frequently pause the play and ask audience members to identify who the next actor will be.

Assessment and Evaluation:

- A formative assessment of the role play in the form of roving interviews.
- A summative assessment can be administered asking students to indicate the number of objects in existence as the play progressed and similar questions.

Accommodations:

- Let pairs of students play a role.
- Assign roles yourself giving simpler roles to students who are struggling.

Resources:

- Several role playing exercises are available at: http://cs.colgate.edu/APCS/Java/RolePlays/JavaRolePlays.htm

ACTIVITY: SHORT PROGRAMMING CHALLENGES IN SCRATCH

Time: 90 minutes

Description: Students construct solutions to short programming challenges that explore interactivity in Scratch and discuss the various solutions and possible applications of these challenges in their programs.

Level: 3

Topics: Apply algorithmic problem solving to solving computational problems.

Prior Knowledge: Students should have some familiarity with the Scratch environment, connecting blocks to create programs, creating sprites, managing program flow, and triggering events.

Planning Notes:

Before the activity, teachers should select challenges to go through with their students based on what Scratch features and computational concepts they would like to explore. For example, the teacher may consider the following challenges:

- Whenever two sprites collide, one of them says: "Excuse me."
  - Scratch features: If, Touching blocks
  - Computational concepts: Condition, Events
- Whenever you click on a sprite, all other sprites do a dance.
  - Scratch features: Broadcast, When Sprite clicked block
  - Computational concepts: Events, Parallelism, Synchronization
- When the score reaches 10, the scene (background) changes.
  - Scratch features: If, Operators, Variables blocks
  - Computational concepts: Condition, Operators, Variables

Find more challenges at: http://scratched.media.mit.edu/resources/short-scratch-programming-challenges

Teaching/Learning Strategies:

For each challenge, teachers should:

- Present students with a challenge. Encourage them to work with their peers to come up with a possible solution.
- After 15 minutes, facilitate a discussion around the diversity of solutions that students developed to address the given challenge. Ask students how they might use their solutions to create other Scratch projects. For example, the challenge "Whenever two sprites collide, one of them says: "Excuse me" can be adapted into a project with a story that involves the interaction of multiple sprites.

Assessment and Evaluation:

In the group discussion, students can articulate their solutions and evaluate the solutions of others to address each challenge.

Accommodations:

Teachers may want to print out the challenges for students to have on hand.

Resources:

- Description and video of Scratch Challenges Activity with a group of educators at http://scratched.media.mit.edu/resources/short-scratch-programming-challenges
- ScratchEd website at http://scratched.media.mit.edu/

A.4 Sample Activities for Level 3C: Topics in Computer Science

ACTIVITY: INTRODUCTION TO OBJECT ORIENTED DESIGN

Time: 3 hours

Description: Students are introduced to the initial steps of applying Object Oriented Design (OOD) to a programming problem and practice applying those steps to a problem which may later be used as a significant programming project

Level: 3C.1 AP Computer Science, 3C.2 Projects

Topics: Fundamental ideas about the process of object oriented program design

Prior Knowledge and Skills: none

Planning Notes:

- Prepare blank diagrams for use as CRC cards and/or object diagrams
- Select examples of problems that can be solved by using object oriented techniques.

Teaching/Learning Strategies:

- Explain the differences between an object oriented and a functional approach to the design of a computer program.
- Have a student explain how a card game (like blackjack) is played.
- Working with the class, identify potential objects involved in the game.
- Working with the class, identify possible operations that might be done by or to a card or one possible object. Students in small groups brainstorm operations for other objects identified as part of the problem.
- Illustrate how the two notations can be used to summarize the analysis so far.
- Discuss possible relationships between objects.
- Show notations for relationships.
- Describe a possible scenario in the game and use developed notations to represent that scenario.
- Have students in pairs describe a second scenario and represent it.
- Share class scenarios and consider whether they collectively represent the range of possibilities especially extreme scenarios.
- Students read the possible problems and select one on which to do an OOD. Students work individually on the first two phases (identify objects and operations).
- Students working on the same problem share results and agree on a "best" set of objects and operations.
- Students individually complete the last two steps.

Assessment and Evaluation:

- A formative assessment of the assigned in-class work in the form of roving conferences.
- A summative assessment applying OOD to a new problem

Accommodations:

- Provide copies of problem descriptions, with important nouns and verbs indicated using a different font or type size. Provide written scenarios for each problem.

Resources:

- Wirfs-Brock, Wilkerson, and Wiener, *Designing Object-Oriented Software*, Prentice Hall, 1990
- Fowler, *UML Distilled: Applying the Standard Object Modeling Language*, Addison-Wesley, 1997.
- Overview of lesson and sample exercises are available at: http://max.cs.kzoo.edu/AP/OOD/OODPresentation/ and http://max.cs.kzoo.edu/AP/OOD/OODSpecifications/

A.5 Additional Resources for Levels 3.C.2 and 3.C.3:

A wide range of resources is available for supporting a Level 3 computer science curriculum.

AP Computer Science Course

The curriculum for all AP CS courses is governed by the topic outline available from The College Board at http://apcentral.collegeboard.com/apc/Controller.jpf.

Courses Leading to Industry Certification

Many of the certification courses provide a prepared curriculum that details the content and order of topics. While implementation of this type of course may be simplified by the information provided, careful evaluation is needed with regard to proprietary content versus general concepts. Information about the content of some certification courses can be found online by searching for the specific certification.

Projects-Based Courses

Projects-based courses can provide targeted education geared toward specific student interests in Computer Science. While these courses can be offered by the local school district, enrolling students in a college-based course should be considered. Computer projects-based courses are often offered in a college or university department of computer science, information technology, or information systems. Computer-based programs of study at the college level are typically well established and provide a variety of current topics. Additionally, a student participating in a college computer course may be eligible for college credit. The secondary school will need to investigate the content of each course to determine if it is appropriate for Level 3C study.

Courses for college credit can be offered on the college campus, at the high school, or via distance education. A course offered on the college campus will place fewer burdens on the high school for supporting special hardware, software, and faculty resources.

Online courses can be taken off-hours or during school time. A student who chooses to take an online course outside of school hours will need access to specified hardware, software, and the Internet. When a college-delivered online course is offered during the school day, it may be possible to schedule several online courses during the same class session, allowing better utilization of faculty time. To support this, the school must also provide access to the required hardware, software, and the Internet.

A course for college credit offered at the secondary school permits the student and high school faculty member to interact in a traditional manner. The secondary school will need to ensure that the curriculum is sanctioned by the college and students are officially enrolled in the college. The college may wish to participate in the selection of the faculty member delivering the course.

Some typical methods by which high school students can achieve college credit follow.

Tech Prep and Articulation Credit—The student takes a course at the high school and receives high school credit. The course is also pre-approved for college credit at a particular college and is typically taught by a high school faculty member. Credit is awarded for the course upon matriculation at that college. The college may require that the student pass a competency exam before applying the credit to the student's transcript.

Dual Credit/Concurrent Enrollment—The student is enrolled in a course for which s/he simultaneously receives high school and college credit. The student must meet all college requirements for entrance into the course.

Challenge Exams—The student may be able to prove proficiency and receive credit by exam. This method is useful for a student who completes a high school course that is not articulated, or who believes s/he has independently gained knowledge of all topics covered by a specific course. The student may be charged a fee to sit for the exam.

Advanced Placement/CLEP Test—A student planning college study toward a career in Computer Science, Information Technology, or Engineering may wish to take an AP Exam in Computer Science. A student planning college study toward a career in Business may wish to take the CLEP Exam in Information Systems and Computer Applications. It is recommended that the student determine how credit will be granted for success on the exam from his/her targeted institution.

Programs that Provide College Credit to High School Students

A number of programs provide college credit to high school students. Here are three examples:

The University of Pittsburgh's College in High School is one example of high schools interacting with a college. The College in High School (CHS) program has offered qualified high school students the opportunity to earn University of Pittsburgh college credits during their regular school day. Students are required to pay a reduced tuition to participate in the program. Financial Aid may be available. The program offers "14 courses to more than 2,900 students in over 100 high schools with more than 200 faculty" (Pittsburgh). At the end of the course, students receive a University of Pittsburgh college transcript. Find information about this program at http://www.asundergrad.pitt.edu/offices/chsp/highschools.html.

The University of Cincinnati Clermont College also offers high school students the opportunity to earn college credit by providing a Post-Secondary Enrollment Options Program (PSEOP). This program permits the student to enroll in the college for college credit only, or to enroll for both high school and college credit. In some semesters, the cost of tuition and books may be paid by the high school and/or college. See http://admissions.uc.edu/highschool/adv_placement/pseop.html for more information.

The University of Northern Colorado provides "High School Concurrent Credit, a program for Colorado Residents enabling high school Juniors and Seniors to earn college credit while in high school" (Colorado). Three options are provided under the program:

> Option I—Fast Track Program: For the student who is a high school senior and has met high school graduation requirements.
>
> Option II—Post-Secondary Enrollment Options Program: For the student who is a high school junior or senior and has not met high school requirements.
>
> Option III—College Acceleration Program: For the student who is a high school junior or senior and wants to accelerate his or her college program whether or not the graduation requirements have been met. (Colorado)

Resources

1. eHow.com, How to Get College Credit Before Attending College, Downloaded 1/29/2011 http://www.ehow.com/how_4424237_getcollege-credit-before-attending.html

3. Arthur R. Greenberg, ERIC Clearinghouse on Higher Education Washington DC, BBB27915, George Washington Univ. Washington DC. School of Education and Human Development, ERIC Identifier: ED347956, Publication Date: 1992-03-00, http://www.ericdigests.org/1992-2/high.htm

4. Comparison of Methods to Receive College Credit for Courses Taken in High School, http://www.tea.state.tx.us/Cate/teched/collegecreditinhs.pdf

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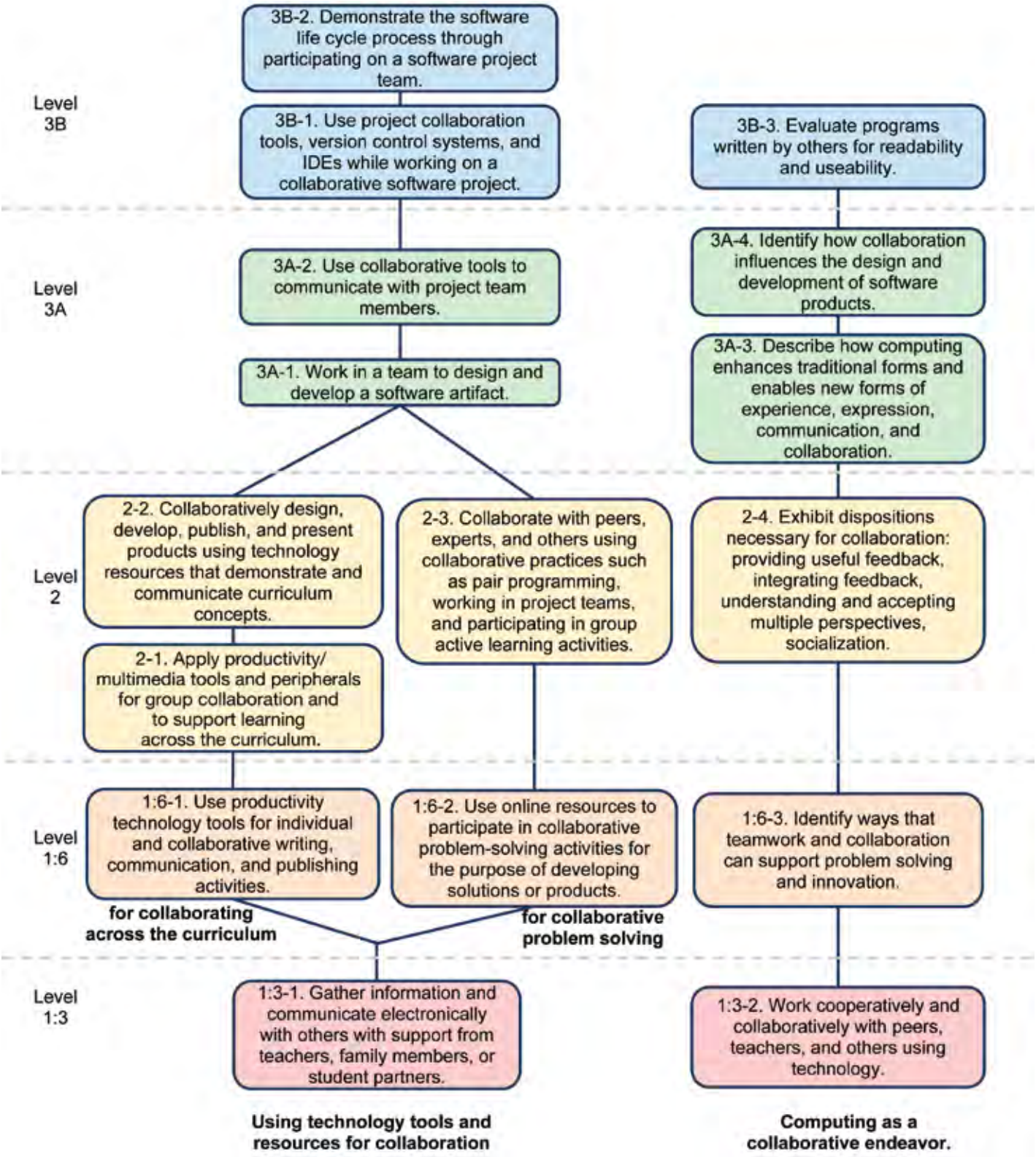
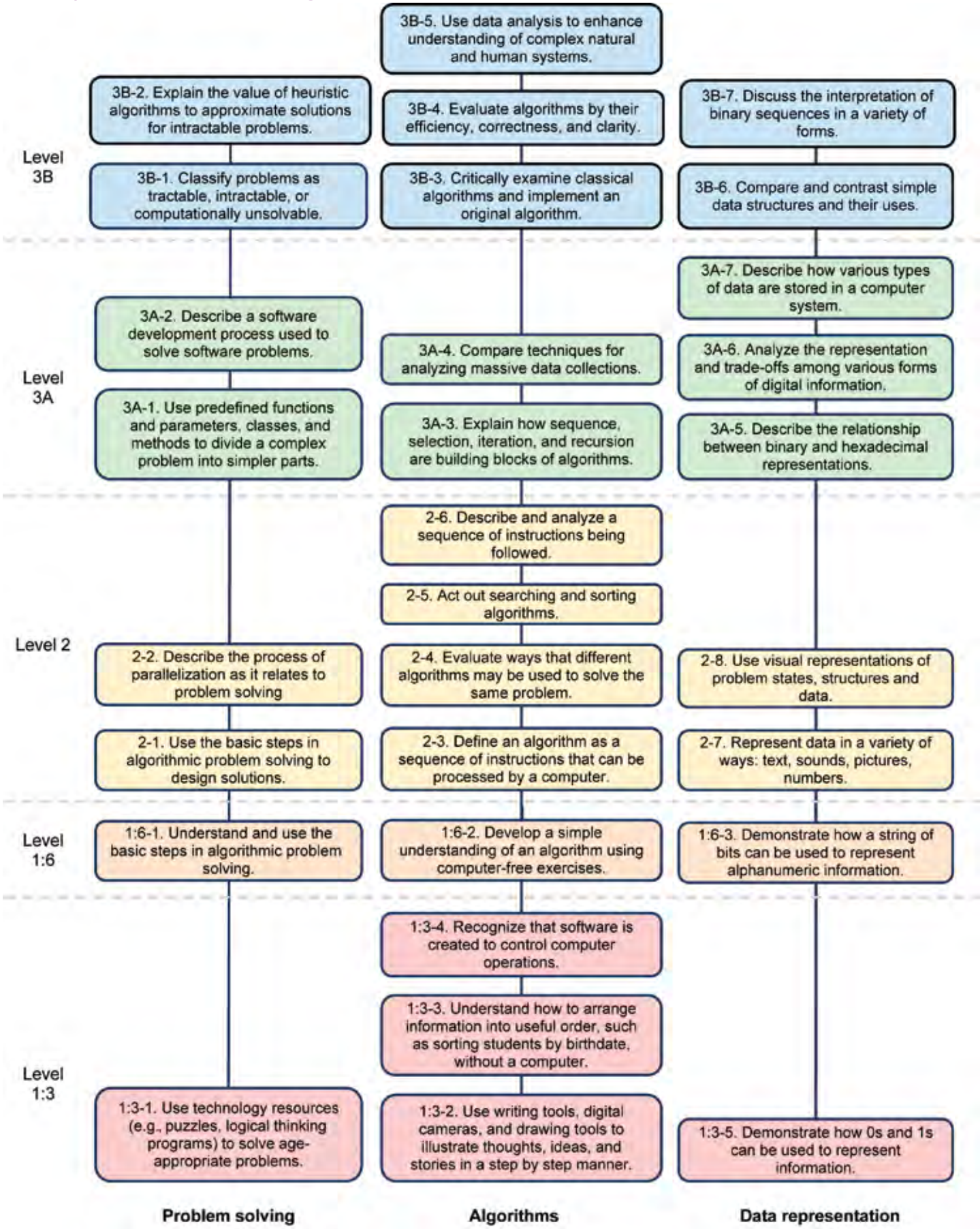
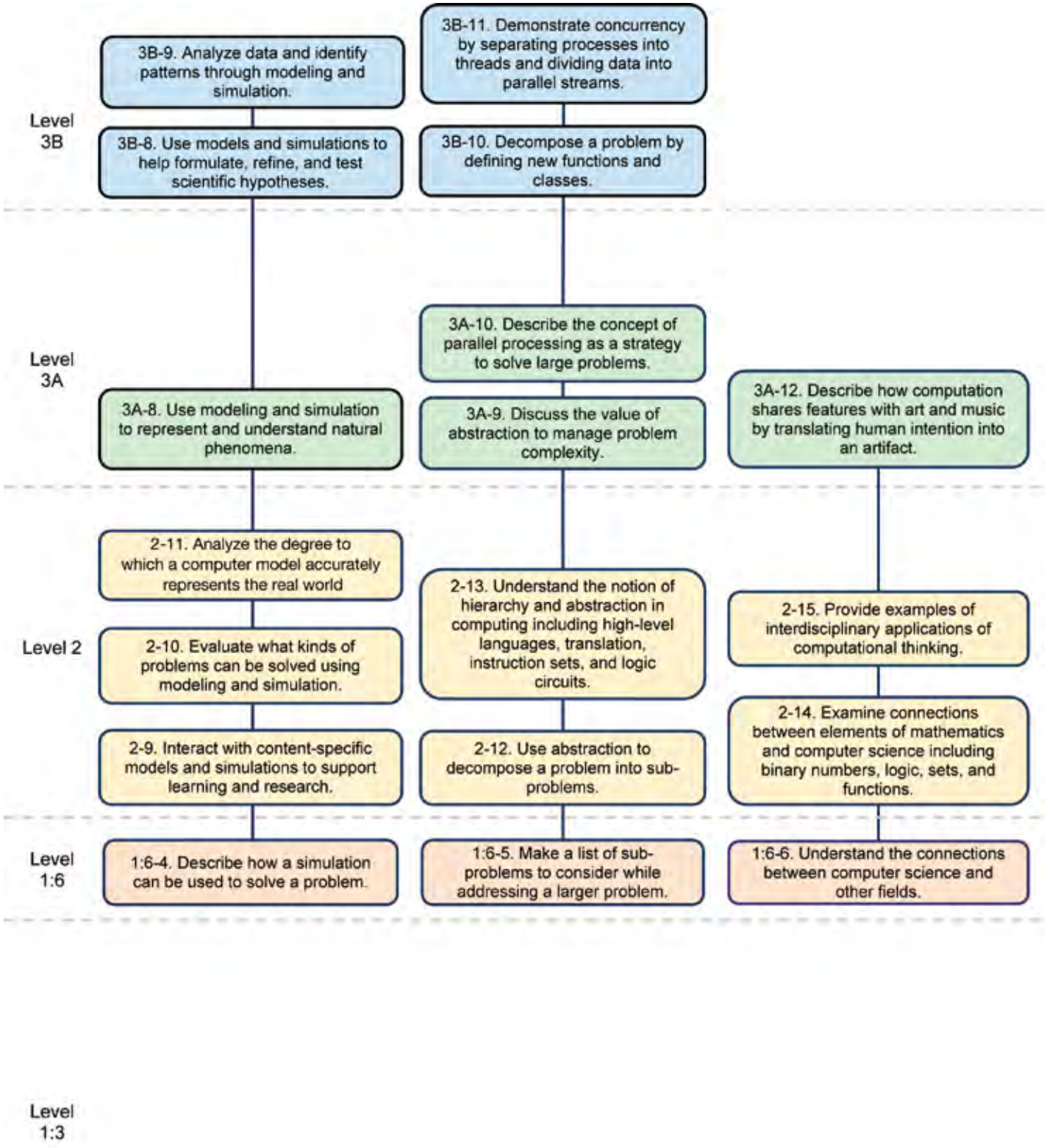
K–12 Standards Scaffolding Charts

Collaboration

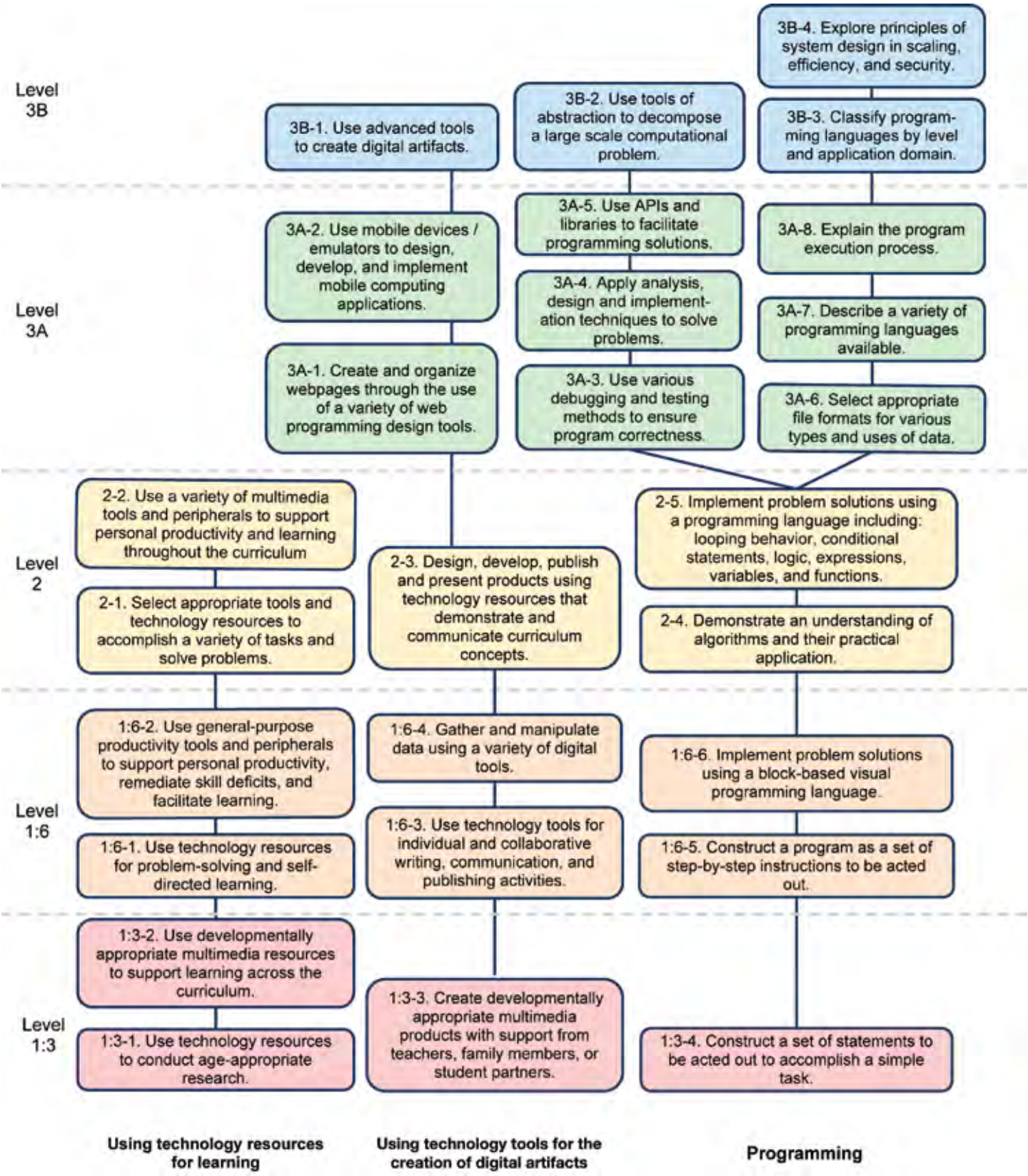


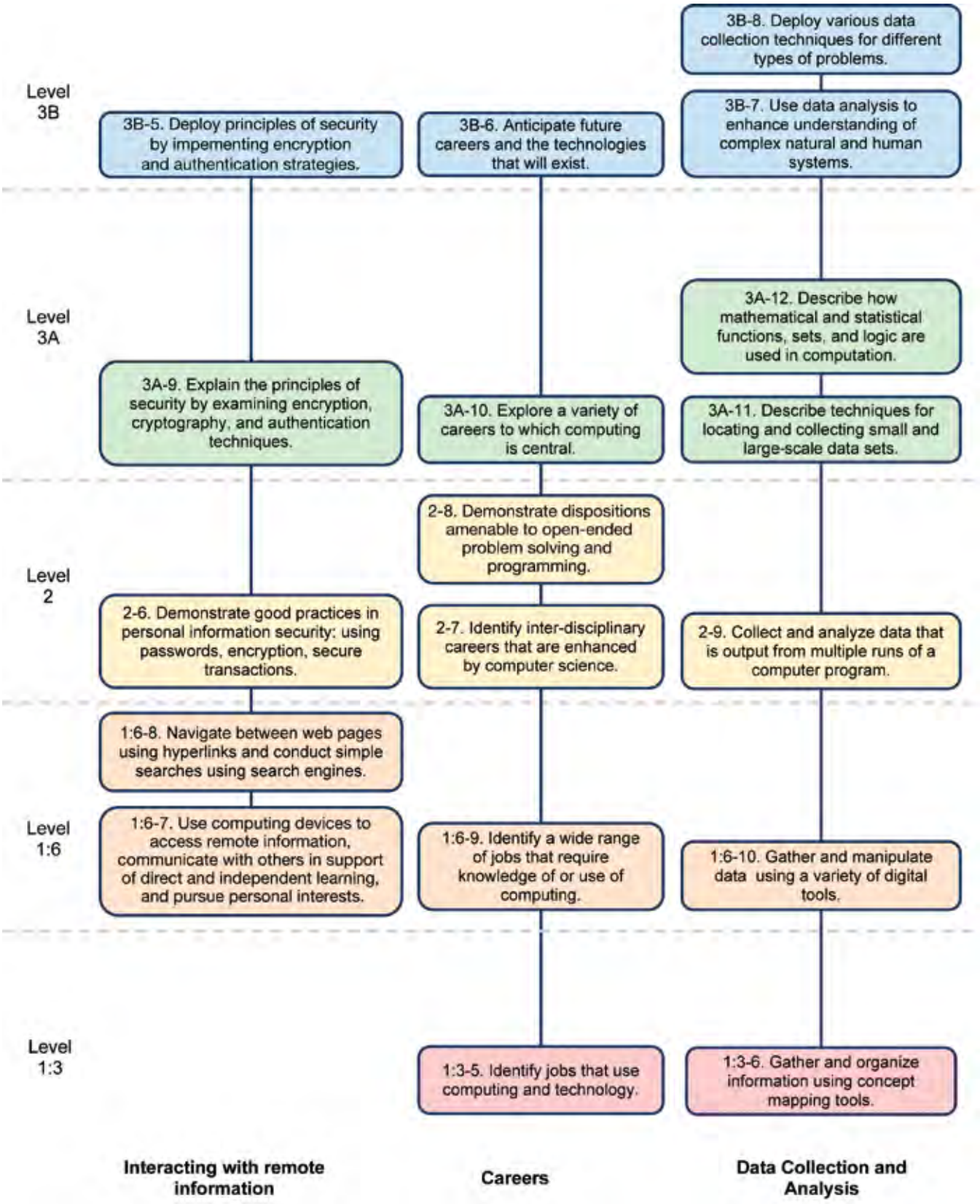
Computational Thinking



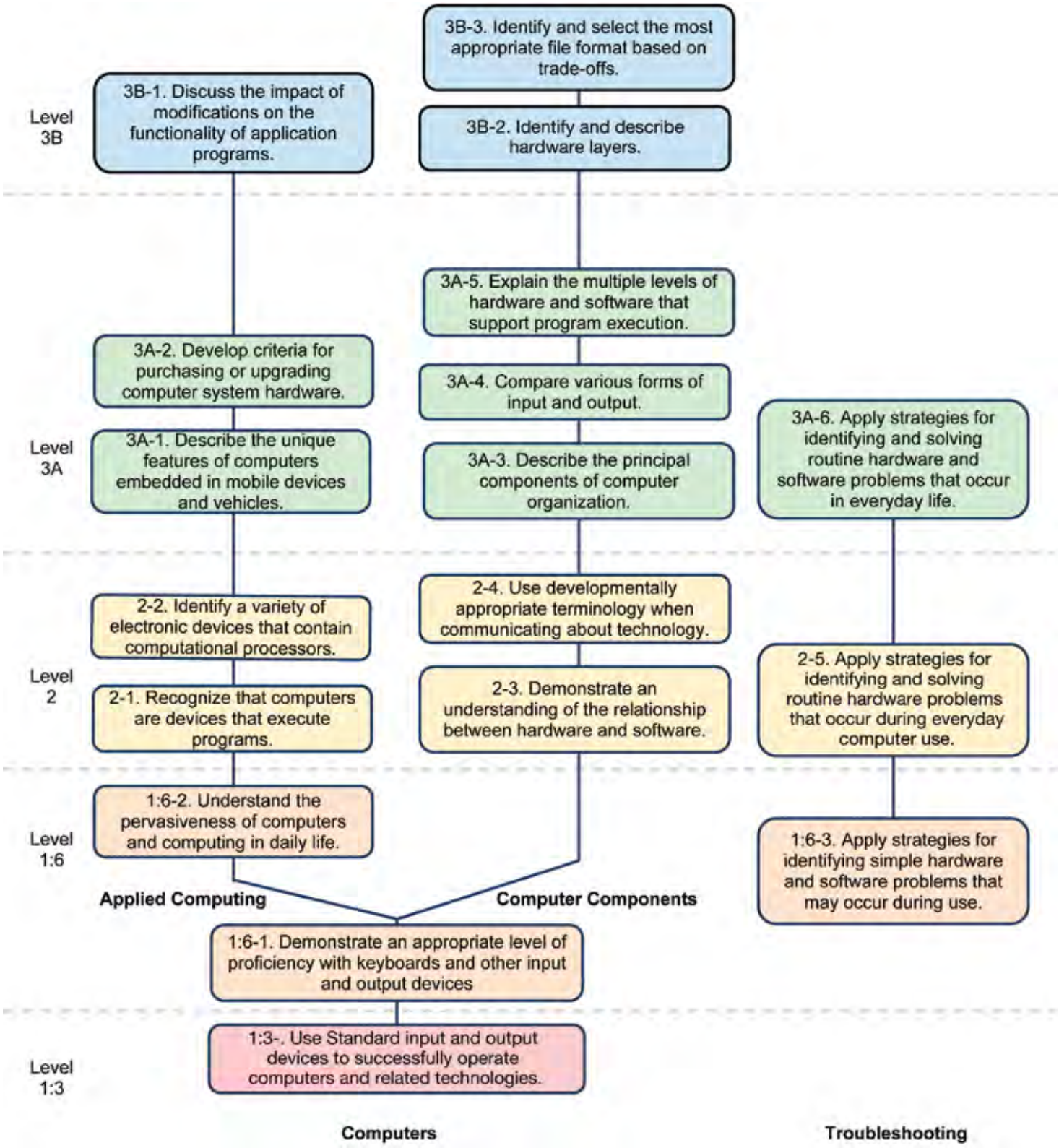

Level 3B
3B-9. Analyze data and identify patterns through modeling and simulation.
3B-8. Use models and simulations to help formulate, refine, and test scientific hypotheses.
3B-11. Demonstrate concurrency by separating processes into threads and dividing data into parallel streams.
3B-10. Decompose a problem by defining new functions and classes.
Level 3A
3A-8. Use modeling and simulation to represent and understand natural phenomena.
3A-10. Describe the concept of parallel processing as a strategy to solve large problems.
3A-9. Discuss the value of abstraction to manage problem complexity.
3A-12. Describe how computation shares features with art and music by translating human intention into an artifact.
Level 2
2-11. Analyze the degree to which a computer model accurately represents the real world
2-10. Evaluate what kinds of problems can be solved using modeling and simulation.
2-9. Interact with content-specific models and simulations to support learning and research.
2-13. Understand the notion of hierarchy and abstraction in computing including high-level languages, translation, instruction sets, and logic circuits.
2-12. Use abstraction to decompose a problem into sub-problems.
2-15. Provide examples of interdisciplinary applications of computational thinking.
2-14. Examine connections between elements of mathematics and computer science including binary numbers, logic, sets, and functions.
Level 1:6
1:6-4. Describe how a simulation can be used to solve a problem.
1:6-5. Make a list of sub-problems to consider while addressing a larger problem.
1:6-6. Understand the connections between computer science and other fields.
Level 1:3
Modeling and Simulation
Abstraction
Connections to other fields

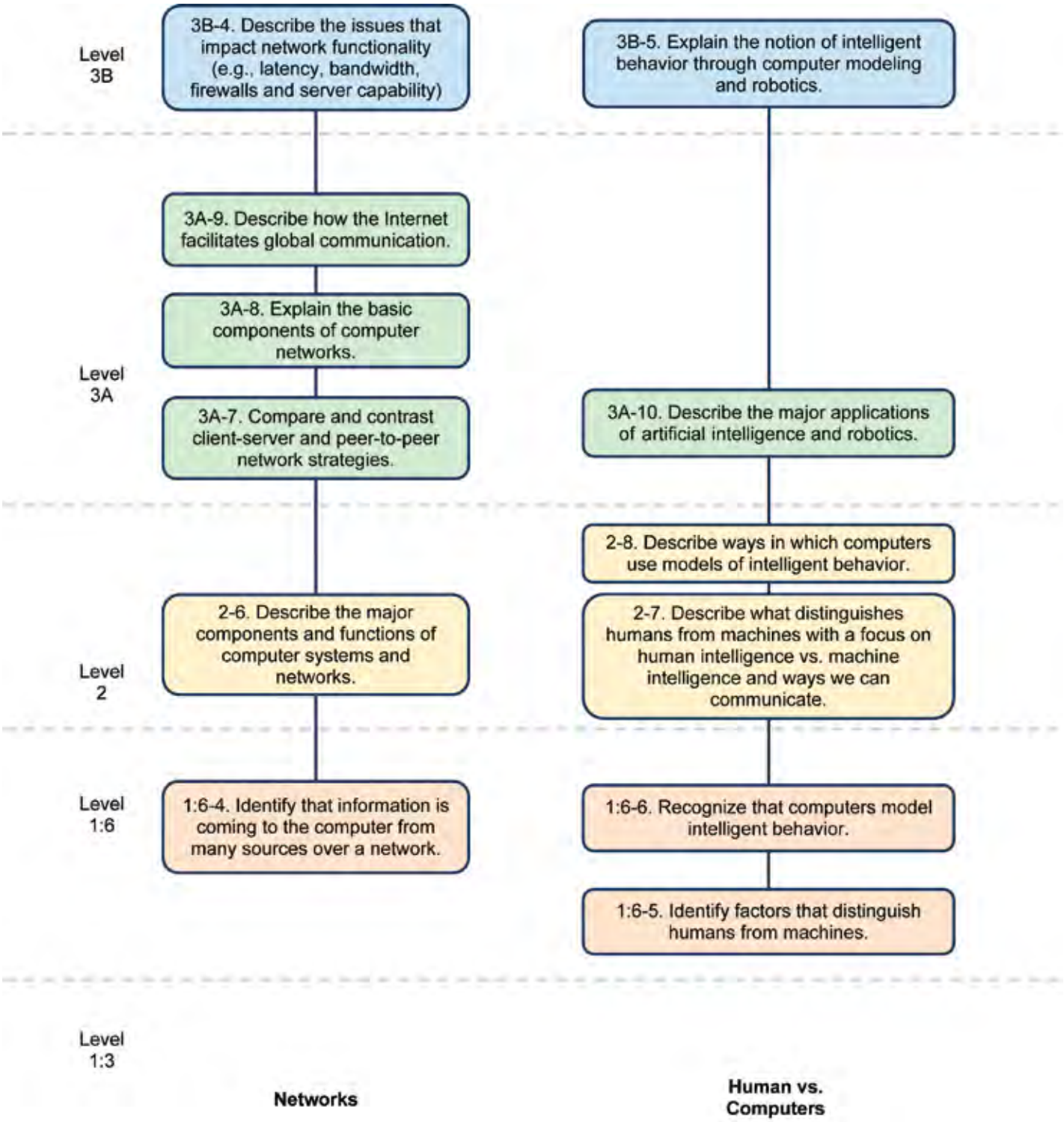
Computing Practice and Programming



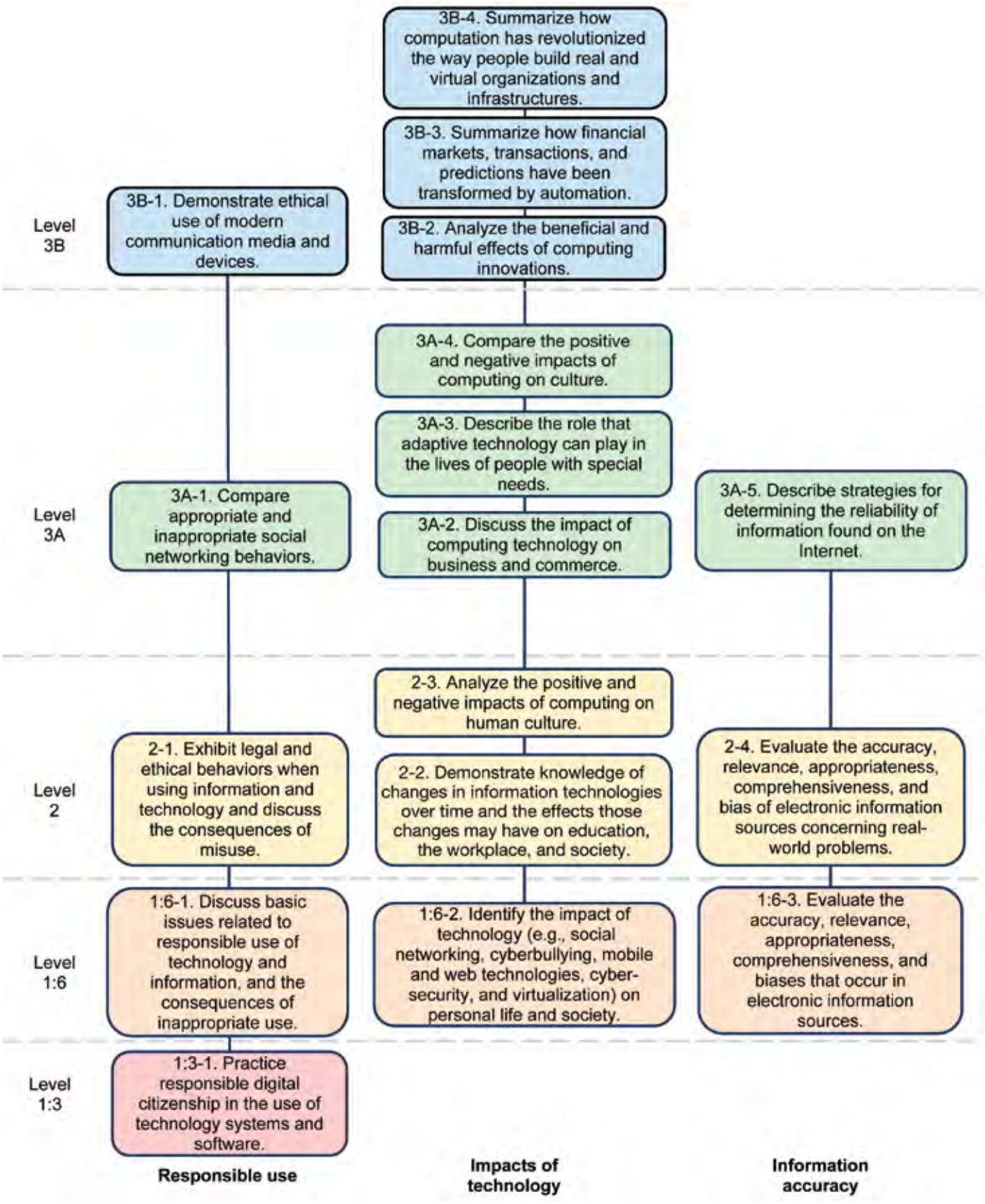

Level 3B
Level 3A
Level 2
Level 1:6
Level 1:3
3B-8. Deploy various data collection techniques for different types of problems.
3B-5. Deploy principles of security by impementing encryption and authentication strategies.
3B-6. Anticipate future careers and the technologies that will exist.
3B-7. Use data analysis to enhance understanding of complex natural and human systems.
3A-12. Describe how mathematical and statistical functions, sets, and logic are used in computation.
3A-9. Explain the principles of security by examining encryption, cryptography, and authentication techniques.
3A-10. Explore a variety of careers to which computing is central.
3A-11. Describe techniques for locating and collecting small and large-scale data sets.
2-8. Demonstrate dispositions amenable to open-ended problem solving and programming.
2-6. Demonstrate good practices in personal information security: using passwords, encryption, secure transactions.
2-7. Identify inter-disciplinary careers that are enhanced by computer science.
2-9. Collect and analyze data that is output from multiple runs of a computer program.
1:6-8. Navigate between web pages using hyperlinks and conduct simple searches using search engines.
1:6-7. Use computing devices to access remote information, communicate with others in support of direct and independent learning, and pursue personal interests.
1:6-9. Identify a wide range of jobs that require knowledge of or use of computing.
1:6-10. Gather and manipulate data using a variety of digital tools.
1:3-5. Identify jobs that use computing and technology.
1:3-6. Gather and organize information using concept mapping tools.
Interacting with remote information
Careers
Data Collection and Analysis

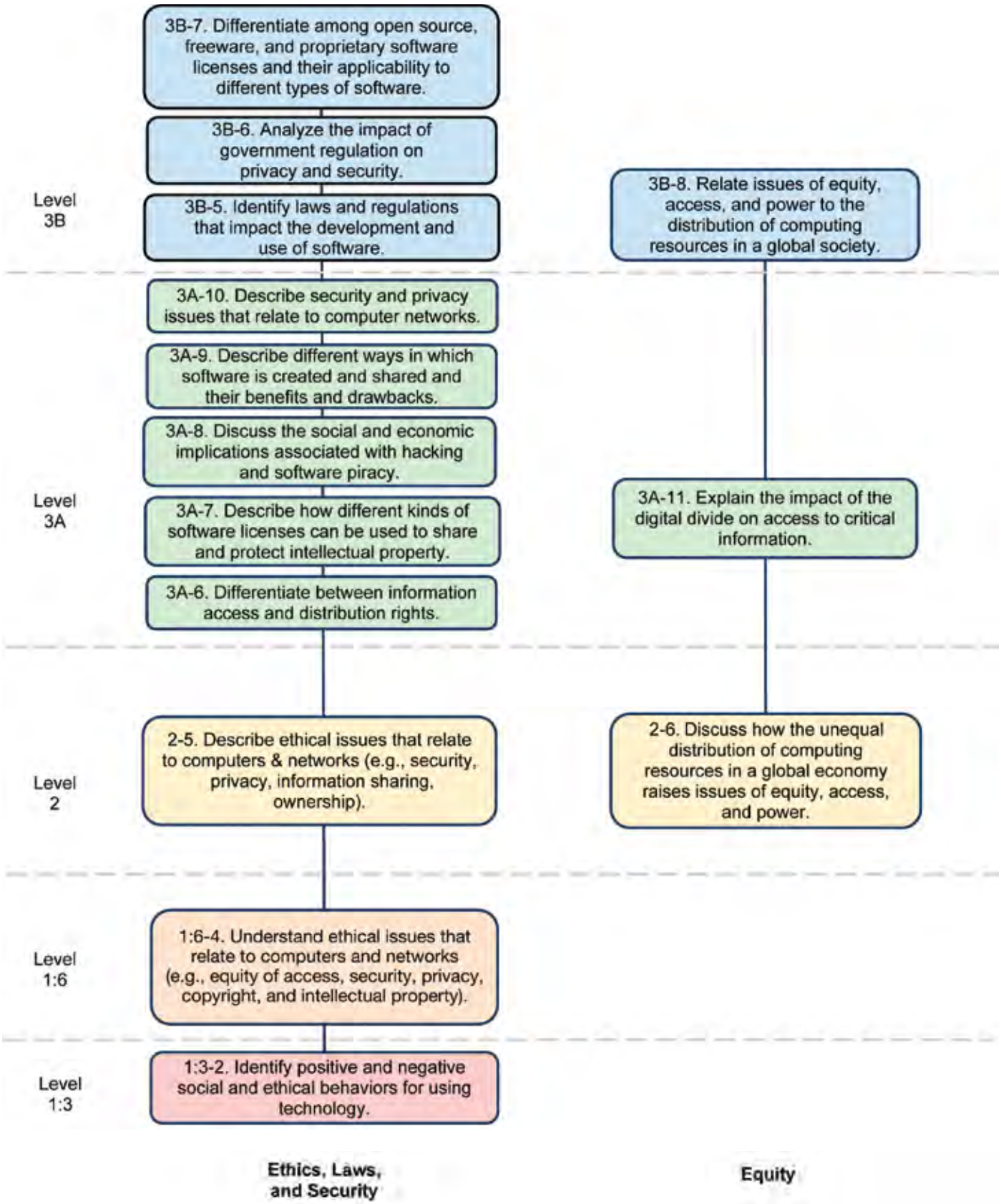
Computers and Communications Devices




Level 3B
3B-4. Describe the issues that impact network functionality (e.g., latency, bandwidth, firewalls and server capability)
3B-5. Explain the notion of intelligent behavior through computer modeling and robotics.
3A-9. Describe how the Internet facilitates global communication.
3A-8. Explain the basic components of computer networks.
Level 3A
3A-7. Compare and contrast client-server and peer-to-peer network strategies.
3A-10. Describe the major applications of artificial intelligence and robotics.
2-8. Describe ways in which computers use models of intelligent behavior.
2-6. Describe the major components and functions of computer systems and networks.
Level 2
2-7. Describe what distinguishes humans from machines with a focus on human intelligence vs. machine intelligence and ways we can communicate.
Level 1:6
1:6-4. Identify that information is coming to the computer from many sources over a network.
1:6-6. Recognize that computers model intelligent behavior.
1:6-5. Identify factors that distinguish humans from machines.
Level 1:3
Networks
Human vs. Computers

Community, Global, and Ethical Impacts




3B-7. Differentiate among open source, freeware, and proprietary software licenses and their applicability to different types of software.
3B-6. Analyze the impact of government regulation on privacy and security.
Level 3B
3B-5. Identify laws and regulations that impact the development and use of software.
3B-8. Relate issues of equity, access, and power to the distribution of computing resources in a global society.
3A-10. Describe security and privacy issues that relate to computer networks.
3A-9. Describe different ways in which software is created and shared and their benefits and drawbacks.
3A-8. Discuss the social and economic implications associated with hacking and software piracy.
Level 3A
3A-7. Describe how different kinds of software licenses can be used to share and protect intellectual property.
3A-11. Explain the impact of the digital divide on access to critical information.
3A-6. Differentiate between information access and distribution rights.
Level 2
2-5. Describe ethical issues that relate to computers & networks (e.g., security, privacy, information sharing, ownership).
2-6. Discuss how the unequal distribution of computing resources in a global economy raises issues of equity, access, and power.
Level 1:6
1:6-4. Understand ethical issues that relate to computers and networks (e.g., equity of access, security, privacy, copyright, and intellectual property).
Level 1:3
1:3-2. Identify positive and negative social and ethical behaviors for using technology.
Ethics, Laws, and Security
Equity

NOTES

NOTES

The first year of your CSTA membership is FREE!

WHAT IS THE COMPUTER SCIENCE TEACHERS ASSOCIATION (CSTA)?

The Computer Science Teachers Association, a limited liability company under the auspices of ACM, has been organized to serve as a focal point for addressing several serious (crisis level) issues in K–12 computer science education, including:

- Lack of administrative, curricular, funding, professional development and leadership support for teachers
- Lack of standardized curriculum
- Lack of understanding of the discipline and its place in the curriculum
- Lack of opportunities for teachers to develop their skills and interests

The above issues result in:

- A profound sense of isolation, and
- Dropping enrollment in college level computer science programs

There are other organizations that address use of technology across the curriculum, but only CSTA speaks directly and passionately for high school computer science.

OUR MISSION

CSTA is a membership organization that supports and promotes the teaching of computer science and other computing disciplines at the K–12 level by providing opportunities for teachers and students to better understand the computing disciplines and to more successfully prepare themselves to teach and to learn.

OUR GOALS

CSTA's organizational and educational goals include:

- Helping to build a strong community of CS educators who share their knowledge
- Providing teachers with opportunities for high-quality professional development
- Advocating at all levels for a comprehensive computer science curricula
- Supporting projects that communicate the excitement of CS to students and improve their understanding of the opportunities it provides
- Collecting and disseminating research about computer science education
- Providing policy recommendations to support CS in the high school curriculum, and
- Raising awareness that computer science educators are highly qualified professionals with skills that enrich the educational experience of their students

OUR SCOPE

The scope of the organization includes:

- High school (all aspects of computer science education)
- Elementary and middle school (introducing problem solving and algorithmic thinking)
- College/university (to establish better transition for high school programs and provide a greater level of support to high school teachers)
- Business and industry (supporting computer science education and teachers)

WHO SHOULD JOIN?

- All High School & Middle School Computer Science Teachers
- All K–12 Computer Applications Teachers
- All individuals interested (and passionate) about K–12 CS Education

The first year of your CSTA membership is FREE!

JOIN US VIA...

web: *http://csta.acm.org/*
phone: 1.800.342.6626
e-mail: *cstahelp@acm.org*

csta Computer Science Teachers Association