The Future of K-12 Computer Science Instruction

Children born since the early 1990s have never known a world in which computer and information technologies are not essential to every aspect of their lives. However, far too many young people, especially low-income and minority youth, lack opportunities to learn about the impact of computer and information technologies on their lives and become savvy consumers, creators, and innovators of those technologies.

Led by Arkansas Governor Asa Hutchinson, the Southern Regional Education Board (SREB) convened the Commission on Computer Science and Information Technology, comprising state legislators, secondary and postsecondary education leaders, the executive director of a state board of education, and experts. The commission met in 2015 and 2016 to determine how states can help more young people, especially girls and students of color, learn computer science and explore exciting computing careers—and for some, to start journeys toward those careers while still in high school.

Commission members believe all students must learn computer science and develop computational thinking skills, not just those considering careers in science, technology, engineering, and math (STEM) fields (box 1). Computer science offers students much more than the knowledge of how computers work or the skills needed to build a device, write code, or manage data. It builds high-level literacy, math, problem-solving, and technological skills and advances efficiency and productivity in every discipline, industry, and profession.

Box 1. Defining Computer Science and IT

A component of STEM, computer science is a distinct academic discipline defined as “the study of computers and algorithmic processes, including their principles, their hardware and software designs, their applications and their impact on society.” IT emphasizes the practical application of technology, specifically the “selection, creation, application, integration, and administration of computing technologies” to meet users’ needs. Other computing disciplines include the following:

- Cybersecurity (also known as information assurance and security) involves the protection of hardware, software, and networks from attacks.
- Information systems (IS) blends technical IT elements with business functions and focuses on the design and implementation of data management solutions.
- Computer engineering grew out of electrical engineering and focuses on the design, construction, and maintenance of computer hardware and software.
- Software engineering involves designing, developing, and maintaining software systems by applying math and computer science principles to engineering design practices.

Although well established at the postsecondary level, computer science is still sometimes confused at the K-12 level with terms like educational technology, the use of computers as a learning tool in instruction; computer literacy or digital literacy, the knowledge of how to use computer technology in an informed way; IT fluency, the ability to learn changing technologies and use them to synthesize and express new information; and computational literacy, the use of analytic skills to solve problems in computing.

A special commission shares five actions states can take to help all students learn computer science and explore computing careers—and for some, start journeys toward those careers while in high school.

by Gene Bottoms and Kirsten Sundell

Box 1. Defining Computer Science and IT

A component of STEM, computer science is a distinct academic discipline defined as “the study of computers and algorithmic processes, including their principles, their hardware and software designs, their applications and their impact on society.” IT emphasizes the practical application of technology, specifically the “selection, creation, application, integration, and administration of computing technologies” to meet users’ needs. Other computing disciplines include the following:

- Cybersecurity (also known as information assurance and security) involves the protection of hardware, software, and networks from attacks.
- Information systems (IS) blends technical IT elements with business functions and focuses on the design and implementation of data management solutions.
- Computer engineering grew out of electrical engineering and focuses on the design, construction, and maintenance of computer hardware and software.
- Software engineering involves designing, developing, and maintaining software systems by applying math and computer science principles to engineering design practices.

Although well established at the postsecondary level, computer science is still sometimes confused at the K-12 level with terms like educational technology, the use of computers as a learning tool in instruction; computer literacy or digital literacy, the knowledge of how to use computer technology in an informed way; IT fluency, the ability to learn changing technologies and use them to synthesize and express new information; and computational literacy, the use of analytic skills to solve problems in computing.

In the global labor market, knowledge of computer science, computer literacy, and computational thinking skills are required in nearly all careers. However, jobs in computer science, information technology (IT), and related fields are an especially large and growing sector of the US economy. By 2020, as many as 4.6 million out of 9.2 million STEM jobs will be computer-related.1 Most computer science-related jobs—by one estimate, over 70 percent—will require a bachelor’s degree or more.2

Jobs in computer science and related fields pay well, and the skills needed for these jobs are in high demand. In 2015, the average median salary of jobs in computer science and IT was $81,430—more than double the $36,200 median salary of all occupations (table 1). Software developers, for example, recently ranked at the top of all jobs advertised online at a mean salary of $92,000.3 Data breaches at corporations like Anthem, Home Depot, and Target sparked a 91 percent growth in US cybersecurity jobs and sent salaries soaring to $100,000 per year or more.4

Nationwide, however, employers in every industry report struggling to find individuals with the requisite computing skills. As a result, many American businesses are recruiting overseas. In 2015, US Citizenship and Immigration Services received 233,000 applications for H-1Bs, also known as skilled-worker visas, which are designed to allow US employers to employ foreign workers in specialty occupations for up to six years. Only 85,000 such visas are allotted each year, mainly in STEM fields.

The college-degreed computing workforce is small, lacks diversity, and must rapidly expand if the United States is to meet labor market demand. Data from the National Center for Education Statistics, the National Science Foundation, and other sources show that only 2.4 percent of college graduates have a degree in computer science.5 Of these, just 8 percent are African American, 8 percent are Latino, and 18 percent are women.6 Less than 1 percent of the technical employees of top Silicon Valley companies like Dropbox, Facebook, and Google are African American.7

Table 1. Computer and Information Technology Occupations

<table>
<thead>
<tr>
<th>Occupation</th>
<th>Entry-level education</th>
<th>2015 Median Pay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer and Information Research Scientists</td>
<td>Doctoral/professional</td>
<td>$110,620</td>
</tr>
<tr>
<td>Computer Network Architects</td>
<td>Bachelor’s</td>
<td>$100,240</td>
</tr>
<tr>
<td>Computer Programmers</td>
<td>Bachelor’s</td>
<td>$79,530</td>
</tr>
<tr>
<td>Computer Support Specialists</td>
<td>Some college or training</td>
<td>$51,470</td>
</tr>
<tr>
<td>Computer Systems Analysts</td>
<td>Bachelor’s</td>
<td>$85,800</td>
</tr>
<tr>
<td>Database Administrators</td>
<td>Bachelor’s</td>
<td>$81,710</td>
</tr>
<tr>
<td>Information Security Analysts</td>
<td>Bachelor’s</td>
<td>$90,120</td>
</tr>
<tr>
<td>Network and Computer Systems Administrators</td>
<td>Bachelor’s</td>
<td>$77,810</td>
</tr>
<tr>
<td>Software Developers</td>
<td>Bachelor’s</td>
<td>$100,690</td>
</tr>
<tr>
<td>Web Developers</td>
<td>Associate</td>
<td>$64,970</td>
</tr>
</tbody>
</table>


Five Actions States Can Take

In their final report, commission members offer states five actions they can take to bridge the computer science opportunity gap and ensure that their citizens have the knowledge and skills they need to prosper in a digital world.
Members agree: Careful planning must underpin each of these five actions. States would be wise to involve many stakeholders in considering the intended and unintended consequences of “computer science for all.” Together, secondary and postsecondary educators, government officials, economic and workforce development agencies, employer partners, parents, and community members all share the responsibility for establishing equitable access to computer science education.

1. Develop Computer Science Standards

Given their authority over standards, graduation requirements, and teacher certification, state boards of education have a key role in making computer science a priority in American schools. Only three states—Arkansas, Texas, and West Virginia—require all high schools to offer computer science (see box 2 on Arkansas).

Too often, students’ choices are limited to basic keyboarding and computer applications that focus on improving digital literacy, not college-preparatory courses like AP Computer Science that truly teach computer science.

Most states lack standards for computer science, and few align their computer science curricula with existing standards. Whether homegrown by states or districts or developed by an organization like the Computer Science Teachers Association (CSTA), rigorous computer science standards not only ensure that all students develop computer science competency and fluency but also ensure that what they learn in the classroom aligns with the rapidly changing “state of the art” of computer science and computing technologies.¹

To meet the goal of helping all students learn computer science, states must begin with filling the standards gap.

---

Box 2. Early Successes of Arkansas’s Computer Science Initiative

A core campaign promise of Governor Asa Hutchinson—computer science for all Arkansas students—became a reality with the passage in 2015 of House Bill 1183, which called for every public high school to offer high-quality computer science courses beginning in the 2015–2016 school year.

Governor Hutchinson set aside $5 million to launch this initiative and address the state’s computer science teacher shortage. He also appointed members of a special task force charged with researching computer science standards and curricula, evaluating the state’s labor market needs, and recommending strategies to meet those needs. A few of Arkansas’s successes to date:

- Just six months after the passage of HB 1183, more than 4,000 Arkansas students had enrolled in computer science courses, with 550 choosing more than one—an increase of 260 percent in one year. The state also saw a 609 percent increase in African-American girls taking coding classes.
- With support from the Computer Science Teachers Association, Code.org, and the Cyber Innovation Center, the Arkansas Department of Education (ADE) created computer science standards for grades K-8 and has nearly completed standards for grades 9-12.
- The state is revising its teacher certification and licensure pathways to align with its standards. To enlarge the teacher talent pool, ADE is retraining teachers through week-long boot camps and virtual professional learning communities, creating postsecondary computer science teacher education pathways, and offering a nontraditional route to licensure.
- In the summer of 2016, ADE will direct about $1 million toward preparing high school teachers to take the computer science Praxis exam and training master teachers on the state’s K-8 standards and newly launched Coding Block for grades 7 or 8.
- The Arkansas Department of Career Education designed a three-year Mobile Applications Development pathway, which teaches students how to develop apps for Android or iOS devices.
Eleven states and four districts are taking part in a collaborative effort to create a K-12 computer science framework that states and districts can use to design their own grade-level standards, curricula, lessons, assessments, and professional development. The framework comprises the computer science concepts and practices all students should know and thus will help students develop as learners, users, and creators of technology.

Once they create standards, state boards of education can use them to create or adopt computer science curricula that appeal to diverse students. The commission’s report offers states examples of well-supported, standards-based, low- or no-cost curricula they can adopt. The learning progression across K-12 looks like this:

- Elementary school students learn computer science concepts and cultivate problem-solving skills through hands-on activities in art, language arts, math, science, and social studies classes. Young children develop computational thinking skills by solving puzzles, using digital media tools to create and illustrate stories, and creating games with visual programming tools. Upper-elementary school students work together to develop apps, explore careers, and discuss social and ethical issues of computing.

- Middle school students blossom when their studies are challenging, meaningful, and personally relevant. Students learn about devices and networks, consider how computing facilitates communication, and work with their peers to solve problems in their communities.

- High school students benefit from broad-based, civics-oriented introductory courses—like Exploring Computer Science and AP Computer Science Principles—that engage and encourage more students, especially girls and students of color, to study computer science and explore computing careers. Students who want to start a journey toward a computing career can dive deeper by taking career pathway courses.

- Across K-12, all students have frequent opportunities to explore computer science through clubs, competitions, camps, summer immersion programs, and extracurricular activities.

### 2. Lay the Groundwork

A strong academic foundation is essential to learning computer science. Yet many American students have poor literacy, math, and problem-solving skills. For example, just 28 percent of ACT-tested graduating high school students meet ACT’s college readiness benchmarks in English, reading, math, and science, according to ACT. Thus, states must design and deliver computer science curricula that advance students’ literacy, math, and problem-solving skills, empowering more students to pursue great opportunities in computing fields.

What skills do students need to learn computer science? Computer science is fundamentally about solving problems, a process that requires high-level literacy skills like the ability to perform research, read complex texts, define problems, and explain the steps of a solution. Software developers need strong writing skills to create user guides, for example. Literacy skills are also essential to coding, the use of programming languages to tell apps and websites what to do.

Computer science demands mathematical literacy because the discipline draws most of its core concepts—like binary numbers, definitions, functions, graphs, linear algebra, logic, probability, proofs, sets, and vectors—from algebra, geometry, calculus, statistics, and discrete math. Software developers creating a video game in which characters move and interact on a two-dimensional playing field are using algebra and geometry to plot positive and negative points on a Cartesian coordinate plane.

Computer science also requires computational thinking skills and personal qualities like creativity and collegiality.

The commission urges state boards and state education agencies to take these steps to further incorporate opportunities to develop literacy, math, and problem-solving skills from the earliest grades and through high school:

- adopt an interdisciplinary, project-based approach to instruction in which K-12 teachers empower students to take ownership of their work and recognize the connections between academics and the real world;

- incorporate applied literacy and math skills in every subject area and grade using research-based professional development frameworks.
education, and careers in computer science or fields that require significant computing know-how.

State boards of education can play a major role in building career pathways. The commission recommends that states convene career pathway advisory councils that bring together secondary and postsecondary educators, workforce development agencies, industry leaders, parents, and other members of the community. These councils can be asked to make recommendations on the following:

- creating career pathways in computer science that offer a sequence of at least four courses that connect seamlessly with postsecondary credential and degree programs and align with a college-ready academic core;
- designing road maps that illustrate the on- and off-ramps students can take to degrees and jobs in computing fields;
- identifying such measures of students’ mastery of computer science knowledge as third-party industry certification exams (e.g., CompTIA A+) and validated assessments (e.g., AP exams) that carry college credit; and
- informing students and parents about their choices and helping them navigate college enrollment and credit-transfer processes.

Table 2 illustrates a four-course sequence in programming for students interested in becoming software developers. In 9th grade, Exploring

### Table 2. Career Pathway Course Sequence in Programming

<table>
<thead>
<tr>
<th>Grade</th>
<th>Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Exploring Computer Science</td>
</tr>
<tr>
<td>10</td>
<td>Applied Course (Digital Media, Animation, Robotics, AP CSP)</td>
</tr>
<tr>
<td>11</td>
<td>Programming I (AP CS A, Java I, C++ I, Python I, Visual Basic I)</td>
</tr>
<tr>
<td>12</td>
<td>Programming II (Java II, C++ II, Python II, Visual Basic II)</td>
</tr>
</tbody>
</table>

* = Courses include dual enrollment options that accelerate attainment of college degrees and credentials.
Computer Science or a similarly accessible course takes a hands-on, project-based approach to introducing computer science concepts and practices. In 10th grade, courses like computer animation, digital video production, game design, or robotics may entice students to pursue deeper studies. In 11th and 12th grade, students might take a two-course sequence in a programming language or two courses in different languages. Dual enrollment courses accelerate students’ progress toward a degree. In all grades, experiential learning brings real-world intensity to learning—culminating in an internship or capstone project.

States can support pathways like these by including measures in their accountability systems that reward districts and schools for offering career pathways leading to postsecondary studies in high-demand computer science and IT fields.

4. Prepare Great Computer Science Teachers

Great teachers spark students’ interest in computer science and thus put more of them on a path to degrees and careers in computing fields. Whatever their background, great computer science teachers are problem solvers with an interest and passion for technology who guide student inquiry and who learn alongside their students instead of having all the answers.

Yet for many new and veteran teachers, acquiring a certification to teach computer science is frustrating and complicated. Most states lack postsecondary teacher preparation programs in computer science, and many offer a confusing array of certifications, endorsements, and licensures that may not even include computer science content or pedagogies.10

Commission members believe the solution is for states to create multifaceted certification and professional development systems that help new and veteran teachers acquire computer science content knowledge and master the pedagogical skills needed to engage diverse learners. States can do the following:

- embed computer science content in preservice preparation programs and in-service endorsement programs for elementary and middle school teachers;
- partner with other states and the Educational Testing Service to design a new computer science Praxis exam that reflects current computer science content and instructional practices;
- work with educator accreditation and certification organizations (e.g., Council for the Accreditation of Educator Preparation, the National Board of Professional Teaching Standards) to add computer science to preparation and certification programs;
- adopt creative compensation strategies—like sign-on bonuses, 12-month salaries, and student loan forgiveness programs—to recruit teachers with know-how and passion; and
- provide time for interdisciplinary teacher teams to engage in shared professional development on designing project-based lessons and assignments that blend literacy, math, and problem-solving skills with computer science content knowledge.

5. Educate Communities

Knowledge, image, access, and equity are the most challenging barriers to computer science education. Few students, especially girls and students of color, are aware of emerging career opportunities in computer science. They may not know anyone with a degree or job in a computing field. Many are not encouraged to take computer science courses or obtain computer science degrees. And studies have shown that students of color, especially in underresourced schools, have fewer opportunities to learn computer science.11

“We have to start by building an understanding of computer science and allowing flexibility within the curriculum to personalize learning around career fields and projects that excite students,” said Donna Johnson, executive director of the Delaware State Board of Education.

American parents want their children to learn computer science. In a recent Google and Gallup poll, two-thirds of surveyed parents—and three-quarters of the lowest-income parents—supported required computer science courses.12 Despite this support, less than half of surveyed teachers, principals, and superintendents thought that computer science was a top priority for their school boards.
Two key strategies can help states educate school leaders—and the whole community—about the value of computer science and computing careers.

First, schools can create career exploratory school cultures through teacher advisement systems in which teachers and counselors together design lessons that help students identify interests and plan for life after high school. Individualized graduation plans, career exploration courses, and career aptitude and interest inventories help students learn about jobs, investigate colleges, and identify their potential. Experiential learning—like job shadows, volunteer experiences, and paid and unpaid internships—help students build confidence, cultivate soft skills, and explore adult responsibilities.

Second, state boards of education in their accountability systems can recognize schools, districts, and communities that incorporate computer science learning opportunities across K-12. They also can create career pathways that bridge high school and higher education and reduce workforce gaps in high-demand fields.

Advice for State Boards

As state boards in the SREB region and across the country advance their computer science initiatives, they can look to neighboring states for their achievements and the obstacles they faced. Arkansas Governor Asa Hutchinson credits his state’s early successes to broad public knowledge of his commitment to computer science, strong legislative support, generous funding, educational leadership, and the enthusiastic response of Arkansas students. By taking these five actions, state boards can support strategic planning and smart policies that empower all students with the knowledge and skills they need to become creators of computer and information technologies—and, for some students, to begin journeys toward fulfilling careers.

3. This is based on 2013 data. A.P. Carnevale et al., The Online College Labor Market: Where the Jobs Are (Washington, DC: Georgetown University Center on Education and the Workforce, 2014).
6. A.P. Carnevale et al., African Americans: College Majors and Earnings (Washington, DC: Georgetown University Center on Education and the Workforce, 2016); Kaczmarczyk and Dopplick, Rebooting the Pathway to Success.