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REPORT PRESENTATION

Data and Computing in K–12 Education

Foundational Competencies

Presenters:

Nicholas J. Horton, Shaundra Daily,
Lindsey Henderson, and Janice Mak



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Data and Computing in K–12 Education

Foundational Competencies

Consensus Study Report

About this report

Conduct a consensus study that will **identify the competencies needed for students to navigate and succeed in the changing computational landscape and describe the role that K–12 education can play** in the development of these competencies.

- What competencies and awareness are needed for learners to **develop basic literacy in data and computing?**
- How are the foundational competencies for these fields related to foundational competencies in other STEM fields?
- What should **relevant learning experiences** look like in practice and how might these experiences be tailored to meet students' interests and lived experiences?
- What are the implications for K–12 curricula?

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Key takeaways

Recent calls for adding computer science, data science, artificial intelligence, and quantum information science to K-12 education **could overwhelm the system if not done carefully.**

Common competencies undergird all these fields and to some extent are already in the K-12 curriculum.

The report identifies multiple ways to engage students, starting in kindergarten, including:

integrating data and computing into science and math classes, explicitly calling attention to data and computing in those classes by **elevating learning goals related to data and computing**, and providing opportunities **for stand-alone courses where appropriate.**

Data and Computing in K-12 Education

Foundational Competencies

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Amherst College

Anna E. Bargagliotti

Loyola Marymount University

Shaundra B. Daily

Duke University

Laura G. DeMarco

Harvard University

Emily E. Edwards

Duke University

Susan Gomez-Zwiep

BSCS Science Learning

Shuchi Grover

Looking Glass Ventures

Lindsey Henderson

Excelined

Victor R. Lee

Stanford University

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Arizona State University

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TERC

Nancy B. Songer

University Of Utah

John A. Underwood

Louisiana Department of Education

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Northwestern University

Aman Yadav

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Data and computing initiatives

Many groups are working to add content related to data and computing to the K-12 curriculum.

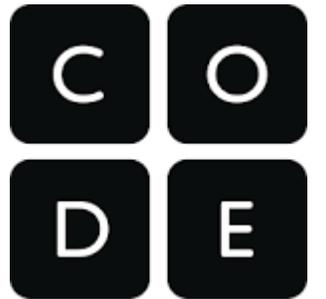
This curriculum is already crowded and figuring out how to add new material is challenging.

As new technologies emerge and data and computing become more central to life and work, the importance of educating students in this area grows.

This report presents an approach for improving data and computing learning for students.



National Q-12 Education
Partnership



Analysis of existing frameworks and standards

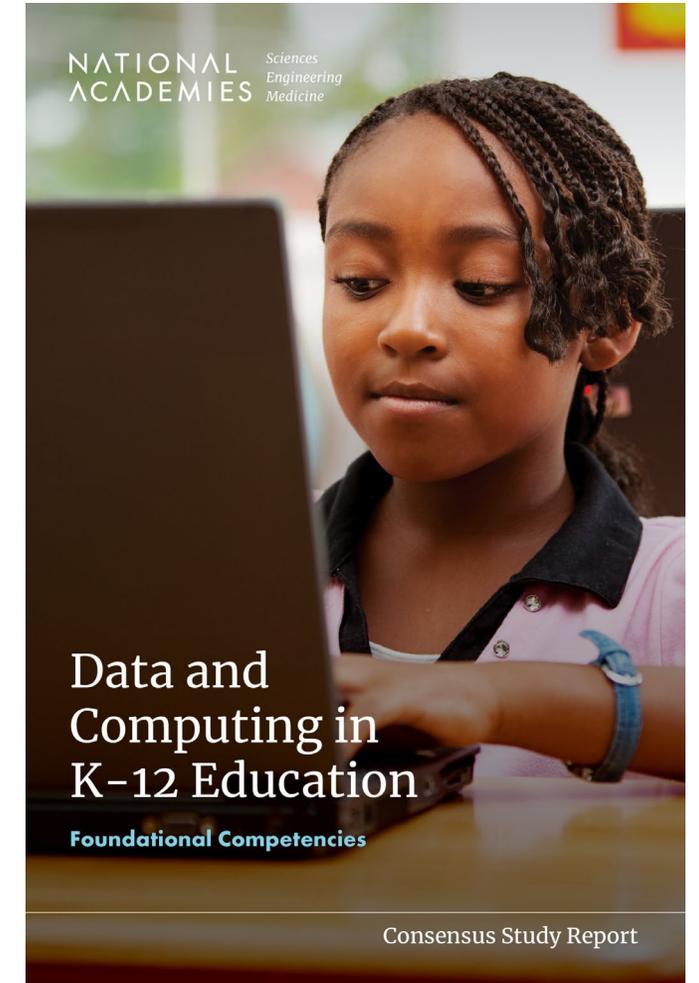
- Computer Science Framework and Standards
- Data Science Progressions
- National Council of Teachers of Mathematics
- Common Core Math
- K-12 Science Framework/Next Generation Science Standards

A young girl with braids is looking at a laptop screen in a classroom. She is wearing a white shirt with a dark collar and a blue wristband. In the background, another student is visible, and there are other laptops on desks. The scene is brightly lit, suggesting a modern educational environment.

Report overview.

Report Contents

- Chapter 2: Current Context (Organizations and Initiatives)
- Chapter 3: Foundational Competencies
- Chapter 4: Elevating the Foundational Competencies
within STEM-related Subjects
- Chapter 5: Effective Learning Experiences
- Chapter 6: Design of Curriculum
- Chapter 7: Preparing and Supporting Teachers of
Data and Computing
- Chapter 8: Transforming the K-12 System
- Chapter 9: Recommendations and Research Agenda



Current Context (Chapter 2)

Efforts to Incorporate Data and Computing into K-12

- Data Science
- Computer Science
- Artificial Intelligence
- Quantum Information Science

STEM Subjects as a context for data and computing

- Math
- Modeling
- Statistics
- Science



Conclusions about Context

Conclusion 2-1: New advances in computing, quantum information, artificial intelligence, and related emergent technologies are currently receiving a lot of attention in many spheres. This raises **important questions about what K–12 students need to learn about these contemporary and emerging topics and technologies** to navigate an increasingly complex world.

Conclusion 2-2: As a result of concerted efforts over the last decade, there has been a **consistent growth in computer science** courses and computer learning activities across all grade bands of K–12. Although **access to such experiences remain uneven**, varying between states, districts and schools, a majority of students in the United States now attend schools that offer some computing education.

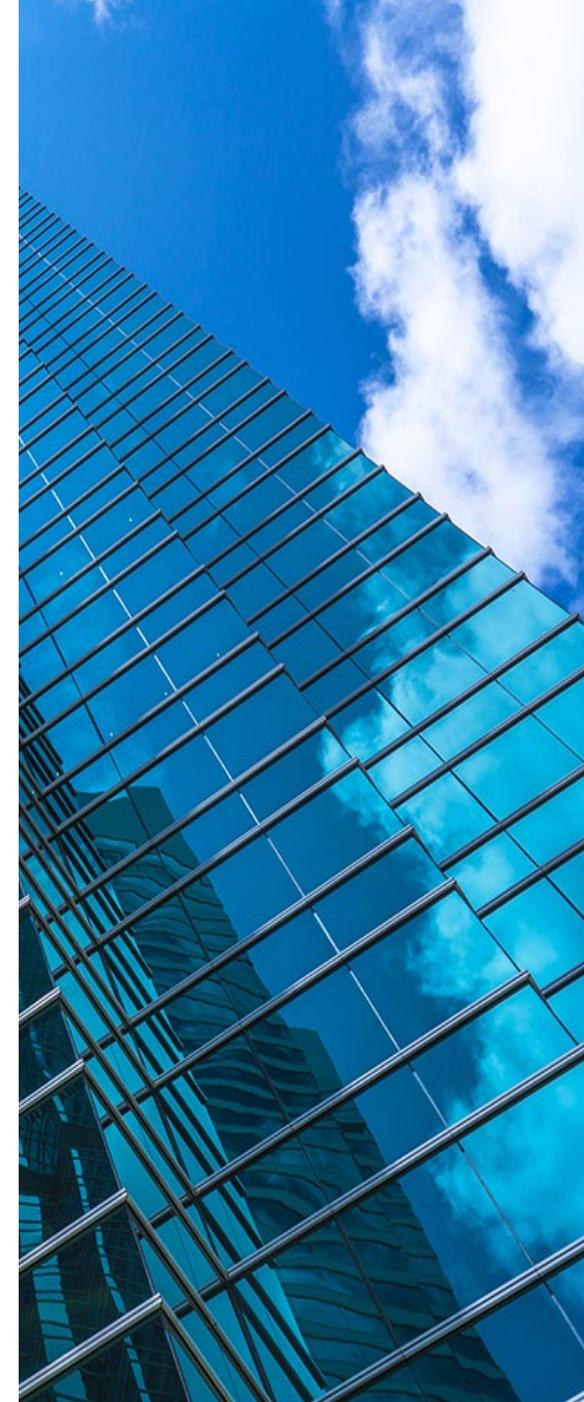


Conclusions about Context

Conclusion 2-3: National conversations are occurring on how to increase what K–12 students learn about data and computing, both through stand-alone courses and through integrating data and computing into other courses. Multiple professional organizations and nonprofits are **independently producing educational standards documents, frameworks, and guidelines** and calling for teacher professional development in data and computing.

If they do not coordinate their efforts, the K–12 education system will miss the opportunity to focus on important features that are relevant across data and computing.

Conclusion 2-4: Adding any new topics to existing K–12 curricula, whether as stand-alone courses or integrated into existing courses, presents **significant challenges for school districts and teachers. Among these is finding space in the curriculum** for new topics, and the time, resources, and capacity for professional development for teachers.



Foundational Competencies (Chapter 3)

Seven Competencies

- Description
- Components
- Examples

Connections between the Competencies

Conclusion 3-3: The foundational competencies identified in this report build upon basic skills **already central to existing school curricula.** To fully engage with the competencies, not only do students need a solid foundation in **mathematics** (e.g., number sense, operations, algebraic thinking, functions, and mathematical modeling) and **science** (concepts, practices, and core ideas), but also other existing school subjects.



Foundational Competency	Description
Problem Posing and Problem-Solving Processes	Students define a problem or question, identify the steps necessary to address it, make an attempt to answer it using tools, reflect on the process, decide on next steps, and iterate.
Producing and Working with Data	Students can both produce data and assess data quality, organize and prepare data for a variety of purposes, and explore and visualize data to begin to answer a question or problem.
Abstraction, Algorithmic Thinking, and Automation	Students deepen their skills with abstraction and logical reasoning to design and express solutions to problems in a systematic, step-by-step way, and to explore concepts and methods of automating data and computing processes.
Probabilistic and Inferential Reasoning	Students identify sources of variability and uncertainty, develop probabilistic understanding, carry out statistical investigations and inference using formal testing procedures, and interpret and generalize results as appropriate.
Models and Representations	Students construct and reason with models and representations to explore phenomena and solve problems. They choose appropriate models for the situation and data available, assess the limitations of models and representations, and recognize the uncertainty inherent in any modeling activity.
Technology and Society	Students recognize, anticipate, and address tensions related to technology and society, values, ethics, and responsibilities.
Data and Computing Systems	Students develop deeper awareness of data and computing tools and systems that provide a foundation to solve more complex problems and address future changes

Elevating the Foundational Competencies Within STEM Subjects (Chapter 4)

- Foundational Competencies within Mathematics and Statistics
- Foundational Competencies within Science and Engineering

Conclusion 4-1: Starting in kindergarten, **students can gradually build more sophisticated knowledge on how to use data and computing to interrogate, evaluate, and make sense of the world around them.** While the identified foundational competencies exist to some degree in current STEM frameworks, **the current attention given to these competencies appears insufficient to prepare students to navigate the increasingly complex and technological world, especially the time spent in elementary school.**



Connecting competencies to math curricula

Conclusion 4-2: Mathematics curricula frequently include some teaching of statistics and sometimes a small amount of attention to aspects of computing. Areas of the existing curriculum such as **measurement, algebraic and algorithmic thinking, probability, and modeling** could be enhanced by more focused and more explicit attention to how they connect to data and computing. For some students, **lessons in statistics and work with data can help motivate and ground mathematics education** and help students see how it is relevant to their lives. **Computing tools and technology can effectively support mathematics instruction** in addition to being a topic of instruction for students.

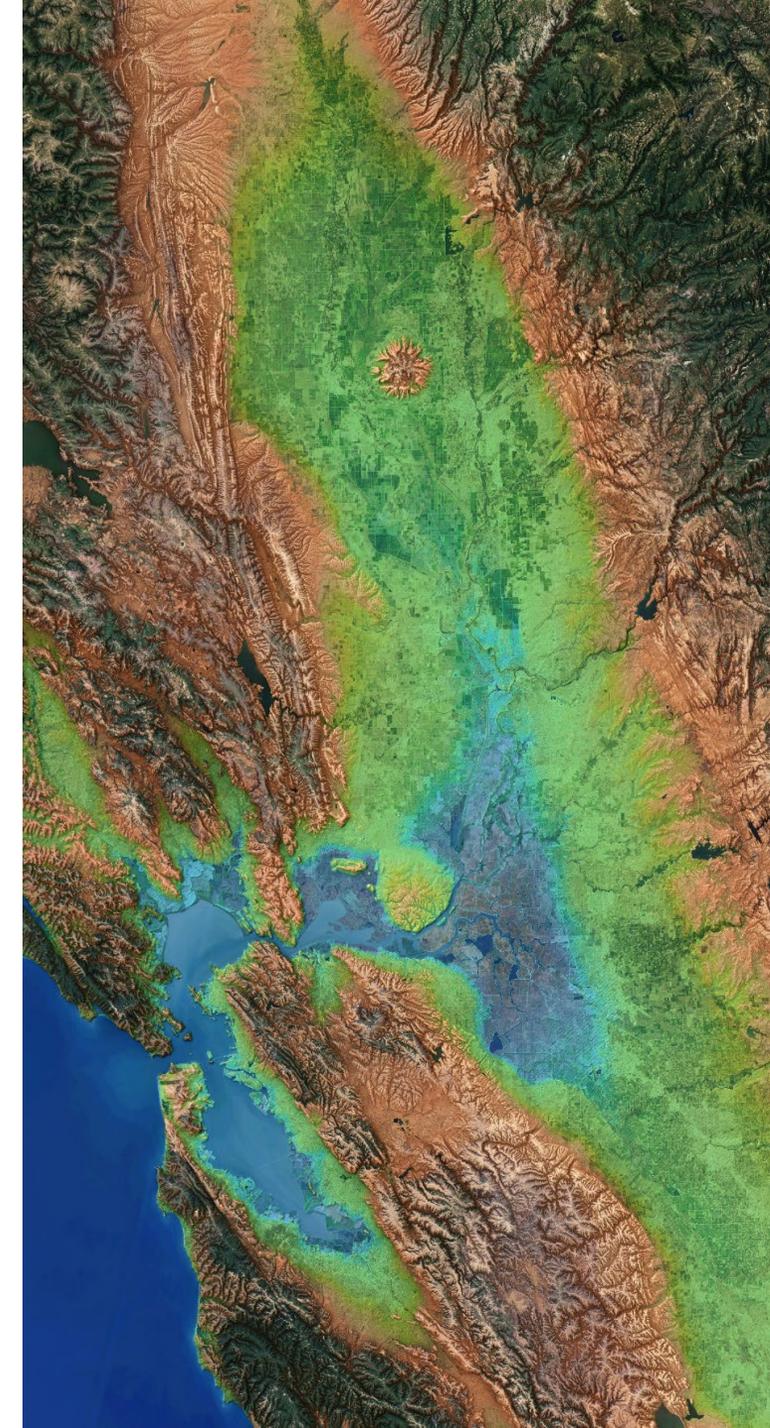
NCTM Process Standards ^a	GAIMME Components ^b	CCSSM Standards for Mathematical Practice ^c	GAISE II Statistical Problem-Solving Process Components ^d
Competency 1: Problem Posing and Problem-Solving Processes			
•Problem solving	•Identify the problem •Make assumptions	•Make sense of problems and persevere in solving them	•Formulate statistical investigative questions
Competency 2: Producing and Working with Data			
•Representation •Connections	•Identifying variables •Do the math	•Reason abstractly and quantitatively	•Collect/Consider the Data •Analyze the data
Competency 3: Abstraction, Algorithmic Thinking, and Automation			
•Reasoning and proof •Representation	•Iterate	•Reason abstractly and quantitatively	•Collect/Consider the Data
Competency 4: Probabilistic and Inferential Reasoning			
•Reasoning and Proof	•Analyze and assess the solution	•Reason abstractly and quantitatively •Construct viable arguments and critique the reasoning of others.	•Interpret the Results
Competency 5: Models and Representations			
•Representation	•Do the math •Implement the model and report results	•Model with mathematics	•Analyze the data
Competency 6: Technology and Society			
•Connections	---	---	•Collect/Consider the data
Competency 7: Data and Computing Systems			
---	---	•Use appropriate tools strategically	---

The Competencies Connect to Science Curricula

Conclusion 4-3: The foundational competencies are related to many concepts that are covered in science curricula, including **scale, proportion and quantity, systems and system models, asking and answering questions, developing and using models, analyzing and interpreting data, and using computational thinking.**

Explicitly bringing the foundational competencies into science courses **would help students see connections between the science concepts and topics in data and computing.**

Disciplinary Core Ideas	Scientific and Engineering Practices
Competency 1: Problem Posing and Problem-Solving Processes	
<ul style="list-style-type: none">• Engineering design—defining and delimiting an engineering problem• Engineering design—developing possible solutions• Engineering design—optimizing the design solutions	<ul style="list-style-type: none">• Science—asking questions• Engineering—defining problems
Competency 2: Producing and Working with Data	
---	<ul style="list-style-type: none">• Analyzing and interpreting data
Competency 3: Abstraction, Algorithmic Thinking, and Automation	
---	<ul style="list-style-type: none">• Using mathematics and computational thinking
Competency 4: Probabilistic and Inferential Reasoning	



Effective Learning Experiences (Chapter 5)

- Scholarship of Learning
- Design Considerations to Support Learning
- Technology and Tool Integration
- Promising Examples of Learning Across Grade Bands (for each competency)



Conclusions about Learning Experiences

Conclusion 5-1: Learning experiences can be designed in **meaningful and relevant ways that recognize and leverage the prior knowledge and experiences of students with data and computing**, engage students with issues of ethics and society, and co-designed to connect to their daily lives, schools, and communities.

Conclusion 5-2: The topics listed in the examples by grade band represent an articulation of the competencies needed for all students to achieve understanding related to data and computing in K–12. Learning about the foundational competencies of data and computing can begin in elementary school. Middle and high school experiences can build on the foundation established in elementary school so that all students develop basic data and computing literacy.



Key Conclusions about Technology

Conclusion 5-3: There are a variety of computational tools available for students to handle multivariate data sets, and there are curated data sets available that can make data more accessible to students when appropriate.

Conclusion 5-4: K–12 students, using a range of powerful digital tools, can **conduct sophisticated statistical analyses, tackle complex computing problems, and utilize advanced artificial intelligence systems** as part of their approach to addressing real-world questions. Such experiences can help prepare them to effectively utilize data and computing.

Conclusion 5-5: A variety of programming environments and several data analysis tools can be used to allow students to engage deeply with the competencies of data and computing. However, there are also **valuable unplugged (hands-on, screen-free) learning experiences** that can help to develop competencies in data and computing and that do not require the use of digital technologies. These unplugged opportunities might be especially powerful for developing conceptual understanding in grades K–8.

Conclusion 5-6: Many K–12 students and teachers are now using generative artificial intelligence (AI). This presents an opportunity for lessons and discussions in schools on the practical and ethical issues related to use of AI, including how to evaluate the validity of AI outputs.

Design of Curricula (Chapter 6)

- Approaches to Integration
- Integrating Data and Computing into Existing Math Curriculum
- Integrating Data and Computing into Existing Science Curriculum
- Promising Approaches by Grade-Band

Conclusion 6-1: The current organization of curricula, courses, and graduation requirements in K–12 provides limited opportunities to introduce new stand-alone courses with content focused on data and computing. **A more coherent curriculum for data and computing can be designed by integrating the foundational competencies into existing school subject areas (such as science, social science, and mathematics) in multiple ways, beginning in elementary school.** This integration approach can help students to grasp the complexities of the topics as well as their connections to other subjects.



Preparing and Supporting Teachers of Data and Computing (Chapter 7)

- What Knowledge is Needed to Teach Data and Computing
- Preparation of Data and Computing Teachers
 - Preservice
 - In-service

*Conclusion 7-1: The principles that should guide the selection of instructional approaches for bringing high quality data and computing content into teaching are not well articulated. This type of **guidance to support coherent integration is needed** for all K–12 teachers and is particularly lacking for K–5 teachers.*



Conclusions about Preservice and In-service

- *Conclusion 7-2: Many teachers will need new knowledge and pedagogical skills as well as more familiarity with data and computing in order to help students learn these foundational competencies. **In-service professional development** can help to improve teachers' ability to teach the foundational competencies in data and computing, yet professional learning is not always supported by schools and districts, and high-quality teacher professional learning on data and computing is not widely available.*
- *Conclusion 7-3: Current **preservice teacher preparation programs** often lack opportunities to learn about the foundational competencies in data and computing. Often, potential teacher candidates are graduating from universities without the skills to facilitate data and computing instruction in K–12. Future teachers for all grades and disciplines would benefit from guidance on how they can support students in working with the foundational competencies. STEM methods courses that include experiences designed to integrate computing and data into STEM teaching and learning could build teacher skills and confidence.*



Transforming the System (Chapter 8)

- System Change at the National and State Level
- System Change at the Local Level
 - School Leaders as Champion
 - Systems for Instructional Support
 - Curricular Materials
 - Engaging Families and Communities
- The Importance of Out-of-School Time (OST) Spaces

Conclusion 8-1: Fully achieving an educational system that prioritizes teaching and learning of data and computing is a complex task given the current structure and constraints of schools and districts. Both short-term and long-term changes are needed to ensure that all students are literate in the foundational competencies and ready to navigate new digital technologies in schools and society. Prioritizing a more coherent and coordinated approach among curriculum developers, advocates for change, families, and educators could begin now and start to improve learning for today's students. Changing policies, especially those related to curriculum and teacher professional learning, might take more time.

:



A young girl with braids is looking at a laptop screen in a classroom. Another student is visible in the background, also working at a computer. The image has a light blue overlay.

**Report
Recommendations.**

Overview of the Recommendations

- **Adding Data and Computing to K-12**
 - INTEGRATION
 - Elevate connections to existing content
 - Start in Kindergarten and continue throughout K-12
- **Supporting Teachers of Data and Computing**
 - Instructional materials that support unplugged and digital learning experiences based on the foundational competencies
 - Preservice and in-service professional learning related to data and computing
 - Resources to support teachers in using the materials
- **Transforming the System**
 - Coordination among efforts to elevate data and computing in schools
 - Access to tools and learning experiences for all students

Recommendations on Adding Data and Computing to K-12

- Recommendation 1: Data and computing are essential to work in STEM and other fields; therefore, state and local education agencies should develop plans to build data and computing into school curricula and courses in a consistent and coherent manner such that these topics are given higher priority across K–12 education. **These changes should be made in a way that enhances foundational mathematics and science learning.** The following principles should be considered to ensure that students have quality learning experiences:
 - In all grades (K–12), learning experiences should focus primarily on **integrating the foundational competencies for data and computing into existing school subjects and providing learning activities that help all students develop the competencies across all content areas.**
 - The opportunity to take stand-alone courses that focus on data and computing should be available to all students. Such courses, while they might be offered in middle school, may be most appropriate in high school.

Recommendations for Local Education Agencies

- Recommendation 2: When selecting curricula to adopt, state and local education agencies should prioritize curricula that **help students see connections between data, computing, and other school subjects**, and that provide students with explicit opportunities across multiple lessons, units, and grades to develop the foundational competencies for data and computing.
- Recommendation 3: State and local education agencies, schools, and teachers should build opportunities for students to engage with data and computing across content areas starting in kindergarten in order to **provide a progression of experiences** that gradually build more sophisticated knowledge to help all students use data and computing to interrogate, evaluate, and make sense of the world around them. These experiences should be during regular coursework, and topics should be accessible to all students and designed to foster success for all students.
- Recommendation 4: States and local education agencies should evaluate how any new courses or requirements related to data and **computing impact existing graduation requirements**. Specifically, they should consider whether the new additions strengthen student learning of science or mathematics and the impact of any new additions on previous expectations for science or mathematics.

Recommendations for Developers of Curricula (part 1)

- Recommendation 5: Curriculum developers and teachers who develop their own instructional materials should **use the foundational competencies as a guide for articulating student learning objectives and designing learning experiences** related to data and computing. This approach should be used for both integrated and stand-alone courses. Learning experiences should incorporate the following features:
 - Students engage in problem-based or project-based experiences that they find meaningful.
 - Students have opportunities to engage in both unplugged (hands-on, screen-free) and plugged in (coding and other digital experiences) lessons and activities.
 - Students use technological tools in ways that help them learn about data and computing (i.e., the foundational competencies), about the tools themselves, and about how to choose among tools for a specific purpose.
 - Students engage in learning experiences about artificial intelligence (AI), and the opportunities, potential uses, tensions, limitations, and risks of AI.
 - Students evaluate how ethics plays a role in decision making related to data and computing, and reflect on the societal impacts of technology used for data and computing, including the practical implications and potential short- and long-term consequences of new and emerging technology.

Recommendations for Developers of Curricula (part 2)

- Recommendation 6: Curriculum developers should design resources that support teachers in carrying out integrated learning experiences that **intentionally bring mathematics, science, and engineering into courses focused on data and computing, as well as experiences that bring data and computing into mathematics, science, and engineering courses**. When data and computing are integrated with other school subjects, they should be **explicitly discussed** to help students improve their understanding of data and computing and to understand how they are connected to ideas in other disciplines. Developers should partner with experts in pedagogy, data and computing, and other relevant content areas in order to determine appropriate learning outcomes and to design resources to support meaningful and effective learning experiences for all students.

Recommendations on Supporting Teachers

- Recommendation 7: Professional development providers should **design opportunities for teachers to experience data and computing competencies within the disciplines they teach, and in the context of the curricula they are expected to implement.**
 - For the generalist teachers (often teachers of grades K–6), professional learning should be **cross-disciplinary** and model the integrated approach inherent in the competencies.
 - For content-certified teachers (often middle and high school teachers), professional learning should be **context specific and focus on how prioritizing engagement with data and computing in courses can enhance student learning.**
- Recommendation 8: Leaders of teacher preparation programs should expand opportunities for **preservice teachers to specialize in computing**, including pathways that leverage partnerships with computer science departments. Comparable partnerships with departments or programs that focus on data (e.g., mathematics, statistics, data science, engineering) may also be appropriate for expanding preservice teacher opportunities.
- Recommendation 9: All **preservice teachers** need opportunities to become familiar with computing and data as part of their preparation. Schools of education and leaders of other pathways for teacher preparation need to provide preservice candidates with:
 - **Opportunities to develop familiarity with the foundational competencies and computing and data broadly.**
 - **Experiences that prepare them to integrate computing and data, specifically the foundational competencies, into the disciplines they teach.**

Recommendations on Transforming the System

- Recommendation 10: State and local education agencies should **design measurements** for student, school, and district participation in data and computing learning experiences to document **offering of both integrated experiences and stand-alone courses and track outcomes** for students who have those experiences.
- Recommendation 11: **Advocates for increasing K–12 student learning about data and computing, professional societies, and other non-profit leadership groups should prioritize efforts to advance teaching of the foundational competencies.** They should work to support state and district efforts to integrate data and computing topics into existing courses.
- Recommendation 12: Efforts to elevate and integrate computing and data across K–12 will require **additional investment and coordination in several areas.** Funders in philanthropy, business, industry, and government, informed by schools, districts, administrators and teachers, should consider providing **support for the development of curricula, professional development, and the purchase and ongoing maintenance of technology.** They should also consider providing support for teachers to take courses or learn from data and computing professionals in ways that allow teachers to develop and bring expertise in data and computing to the classroom. **Investments in education should not be contingent on the procurement of proprietary technologies and/or the collection of student or teacher data.**

Recommendations on Transforming the System

- Recommendation 13: In selecting technological tools to be used in instruction related to data and computing, administrators and educators should:
 - Develop policies and allocate funding to promote digital and physical accessibility, including compliance with the Americans with Disabilities Act (ADA), to **allow use of the tools by all students and teachers.**
 - Invest in **professional development so that teachers are able to use existing tools effectively** and have the ongoing support to integrate new tools.
 - Allocate funding for the costs of initial purchase as well as the costs of on-going maintenance, upgrades, and technical support.
 - Develop policies related to data access and student privacy.
- Recommendation 14: **Professional societies** related to mathematics, science, data science, statistics, and computing and those focused on education in these disciplines should consider revisiting their K–12 frameworks to elevate and highlight the foundational competencies in order to **facilitate the ability of educators to see the connections between frameworks from different disciplines.** These organizations should also **coordinate with each other** and in so doing signal to their communities the urgent need for **increased coherence in efforts to improve student learning.**

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Selected Items from the Research Agenda

- What progressions, sequences, and bridge techniques support increased sophistication in using the complex tools of computing and data science (e.g., unplugged >> blocks >> text-based)?
- What is a coherent and developmentally appropriate sequence of topics and experiences for students to learn about technology, ethics, and society in the context of data and computing?
- What are the most effective professional development models for fostering data and computing integration into STEM and non-STEM disciplines?
- What are effective ways to measure student learning and achievement in data and computing?
- What are the implications of increased emphasis on data and computing for the math curriculum, especially, but not only, in high school? What would a “modern” math curriculum look like?

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