NATIONAL ACADEMIES Sciences Engineering Medicine

REPORT PRESENTATION

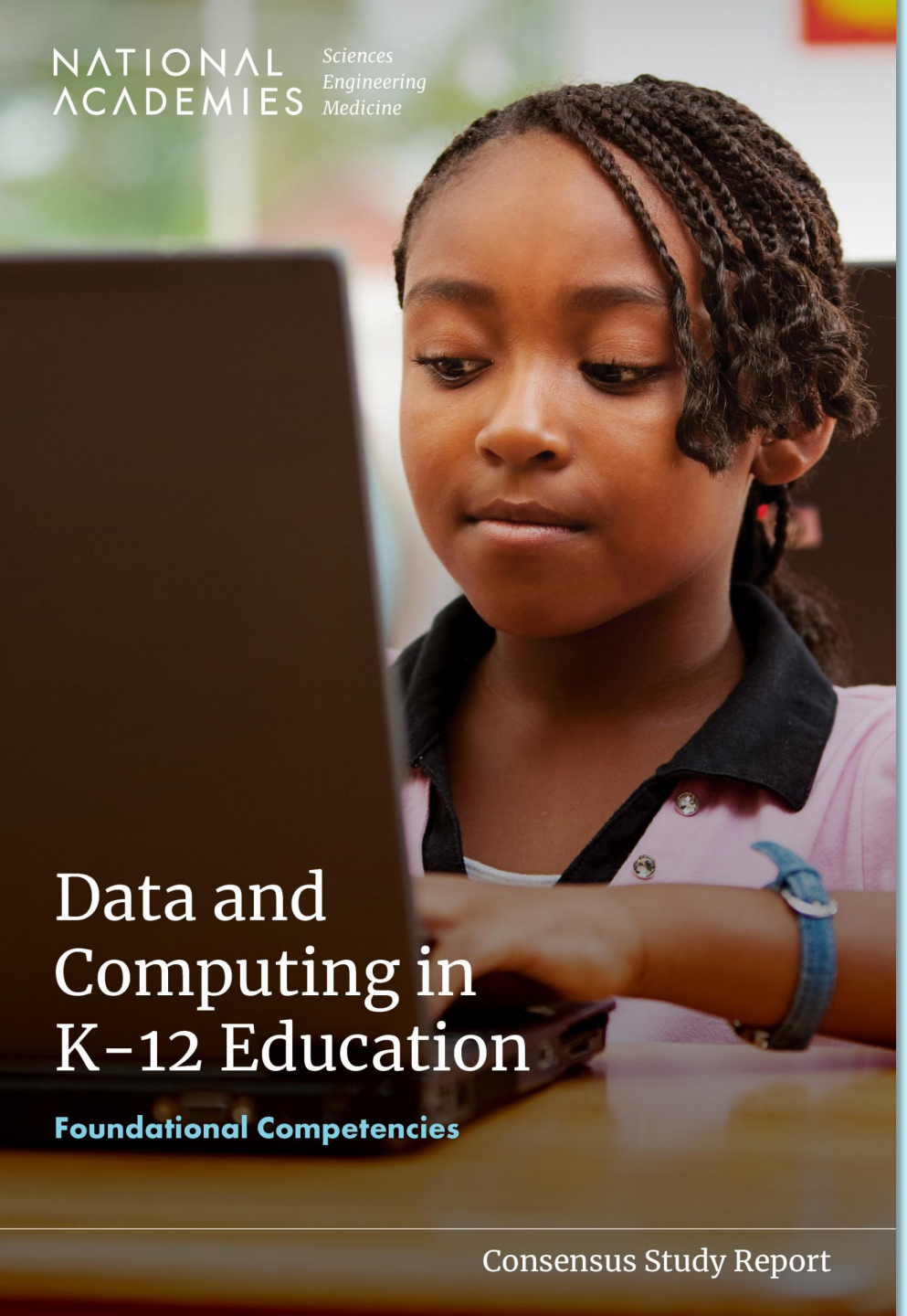
Data and Computing in K–12 Education

Foundational Competencies

Presenters:

Kerry Brenner, Nicholas J. Horton, and Joshua Rosenberg

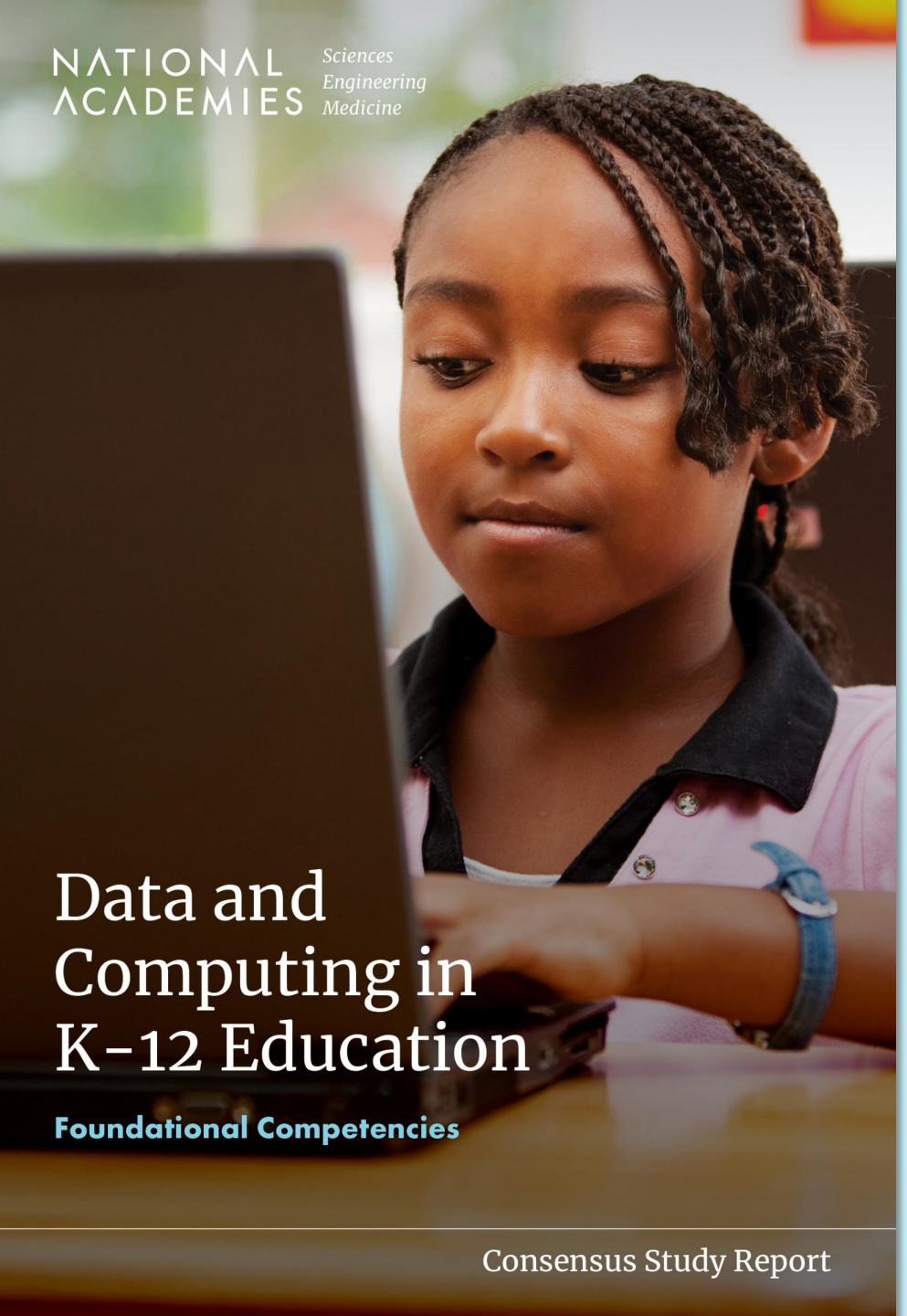
Download the report
nationalacademies.org/data-computing-ed



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?



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.**

Study committee

STUDY CHAIR
Nicholas J. Horton
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

Janice K. Mak
Arizona State University

Joshua M. Rosenberg
University of Tennessee, Knoxville

Andee Rubin
TERC

Nancy B. Songer
University Of Utah

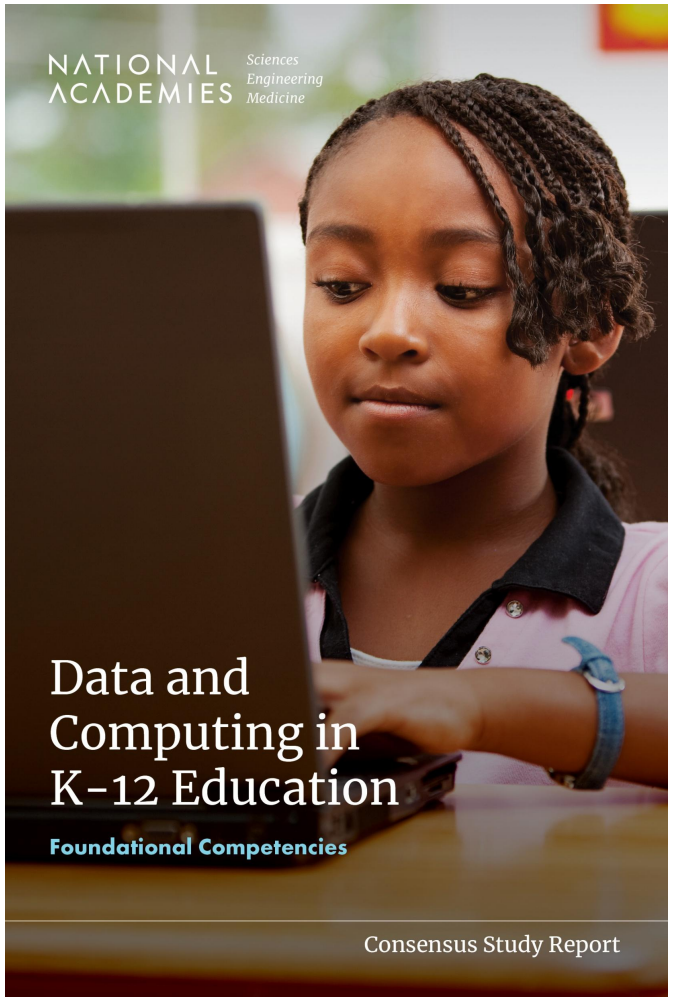
John A. Underwood
Louisiana Department of Education

Sepehr Vakil
Northwestern University

Aman Yadav
Michigan State University

Report overview.

Report Contents



Current Context (Chapter 2)

Efforts to Incorporate Data and Computing into K-12

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

STEM Subjects as a context for data and computing

- Math
- Statistics
- Science

Data and computing initiatives

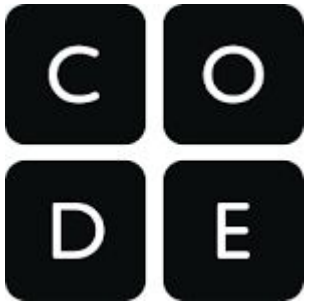
Many groups are working to add content related to data and computing to the K–12 curriculum.

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

Foundational Competencies (Chapter 3)

Seven Competencies

- Each includes a Description
- Some Components
- Some 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.

Competency 1: 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.

- Define a problem or question
- Identify the steps needed to address the problem or question
- Reflect and iterate

Competency 2: 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.

- Produce data: measurement and data provenance
- Organize data: case/attribute structure and data moves
- Exploration and data visualization

Competency 3: Abstraction, Algorithmic Thinking, and Automation

Students deepen their skills of 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.

- Creating abstractions in different contexts and applying them in programming
- Developing algorithmic thinking for different problems and small and large scales
- Recognizing, creating, and utilizing automated solutions for problem solving

NATIONAL ACADEMIES Sciences Engineering Medicine

Competency 4: Probability 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.

- Identify sources and impacts of uncertainty and variability
- Recognize the roles of probabilistic, statistical, and deterministic reasoning and apply them in the context of models and applications
- Make inferences and predictions with appropriate degrees of certainty

Competency 5: 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.

- Construct and use models and representations
- Assess the quality of models and representations
- Recognize limitations of all representations and models

NATIONAL ACADEMIES Sciences Engineering Medicine

Competency 6: Technology and Society

Students recognize, anticipate, and address tensions related to technology and society, values, ethics, and responsibilities.

- Reasoning about process (how a task is accomplished) and product
- Reasoning about self and society

Competency 7: 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.

- Recognizing elements of data and computing systems
- Selecting and using data and computing systems
- Ownership, openness, and access

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.**

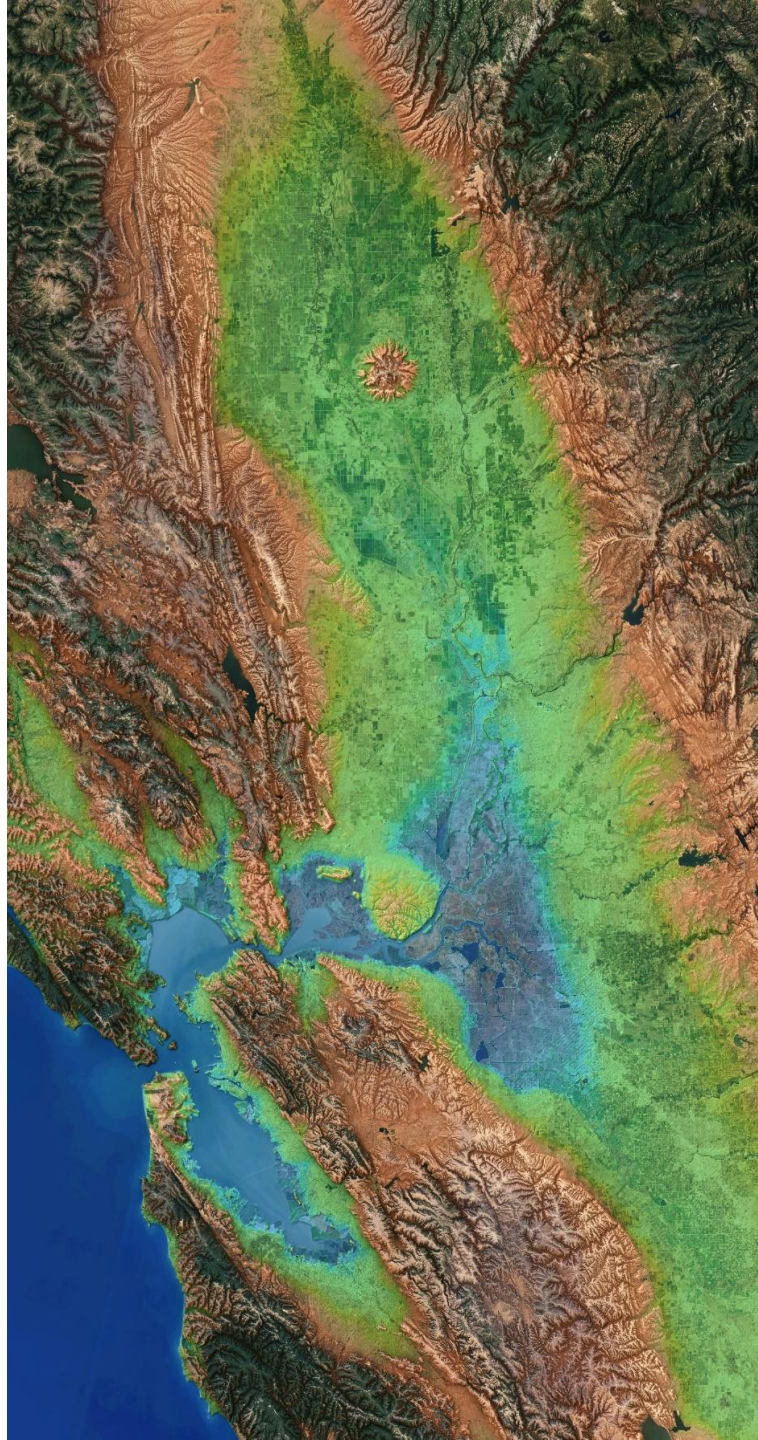
NATIONAL ACADEMIES Sciences Engineering Medicine

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	
• Engineering design—defining and delimiting an engineering problem • Engineering design—developing possible solutions • Engineering design—optimizing the design solutions	• Science—asking questions • Engineering—defining problems
Competency 2: Producing and Working with Data	
---	• Analyzing and interpreting data
Competency 3: Abstraction, Algorithmic Thinking, and Automation	
---	• Using mathematics and computational thinking
Competency 4: Probabilistic and Inferential Reasoning	



NATIONAL ACADEMIES Sciences Engineering Medicine

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	---

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.

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.*

NATIONAL ACADEMIES Sciences Engineering Medicine

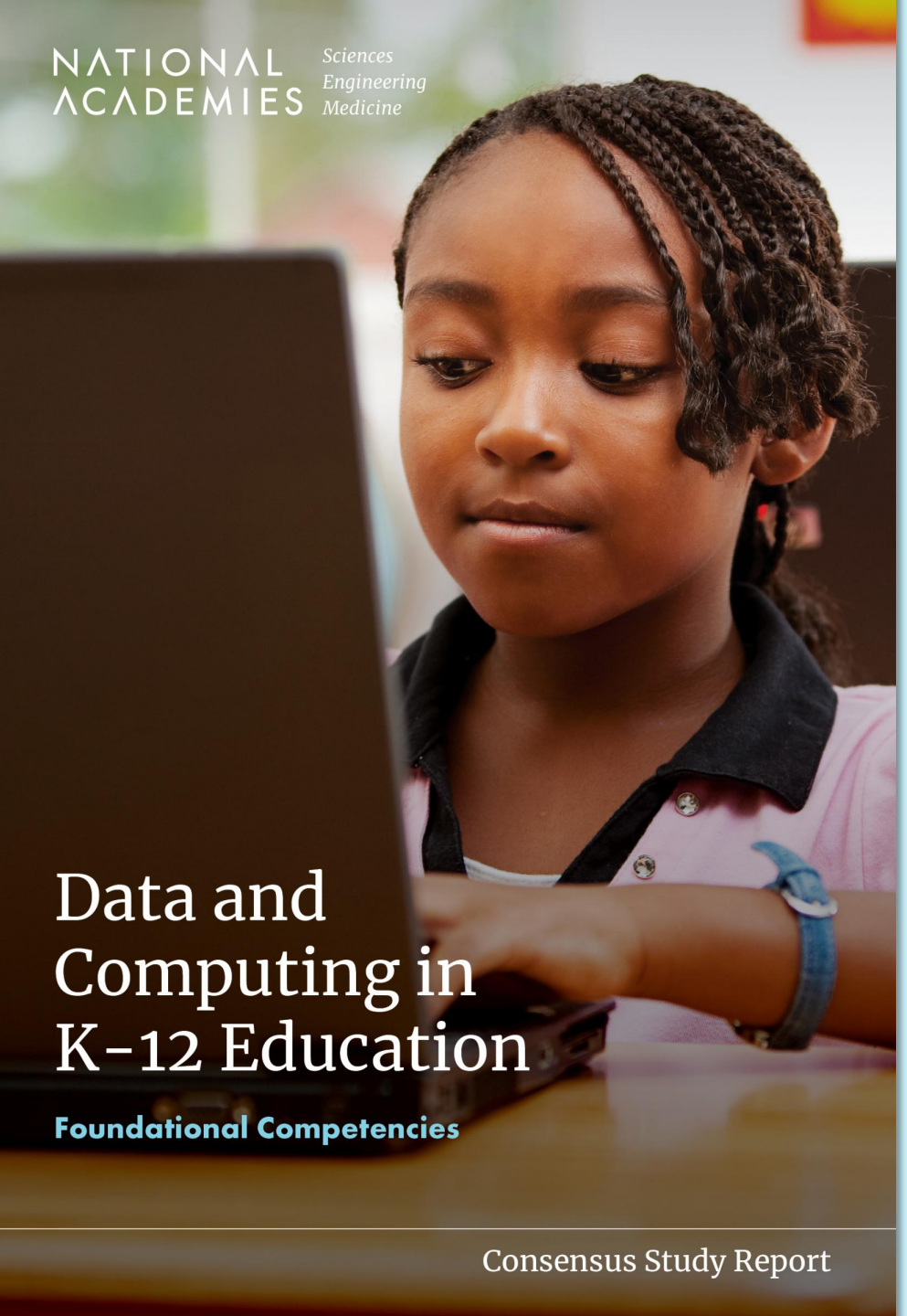
Conclusions about Preservice and In-service

- *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.*

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



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?

Key Takeaways

Risk of overload

Calls to add CS, data science, AI, and QIS to K–12 education could overwhelm the system if not done carefully and coherently.

Common ground already exists

Shared competencies undergird all of these fields — and to a meaningful degree are already embedded in the K–12 curriculum.

Three paths to better learning

(1) Make existing data & computing connections more explicit. (2) Enhance connections in science and math. (3) Expand the role of data & computing in K–12 learning experiences — starting in kindergarten.

nationalacademies.org/projects/DBASSE-BOSE-23-04

Reflections and Implications

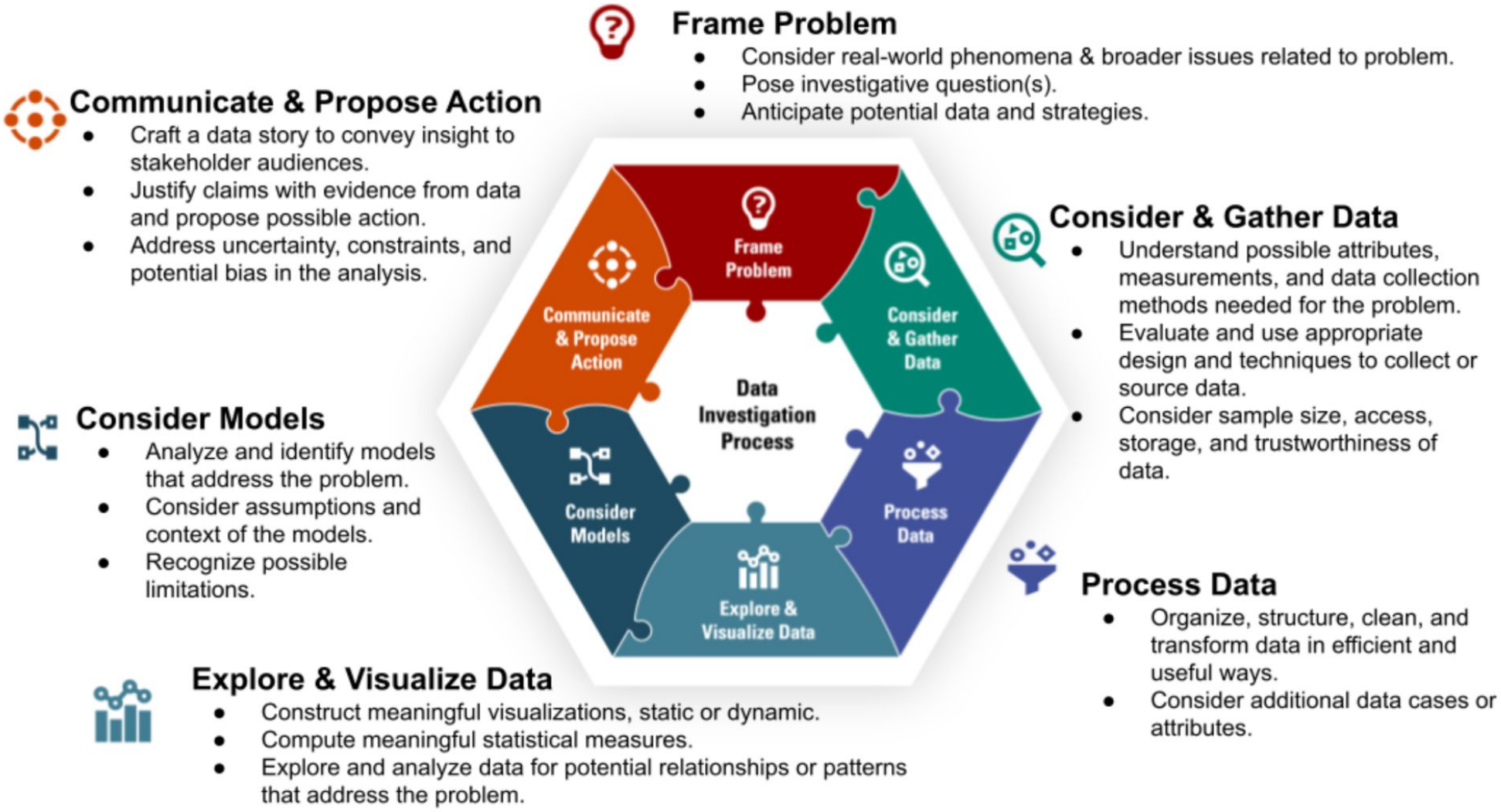
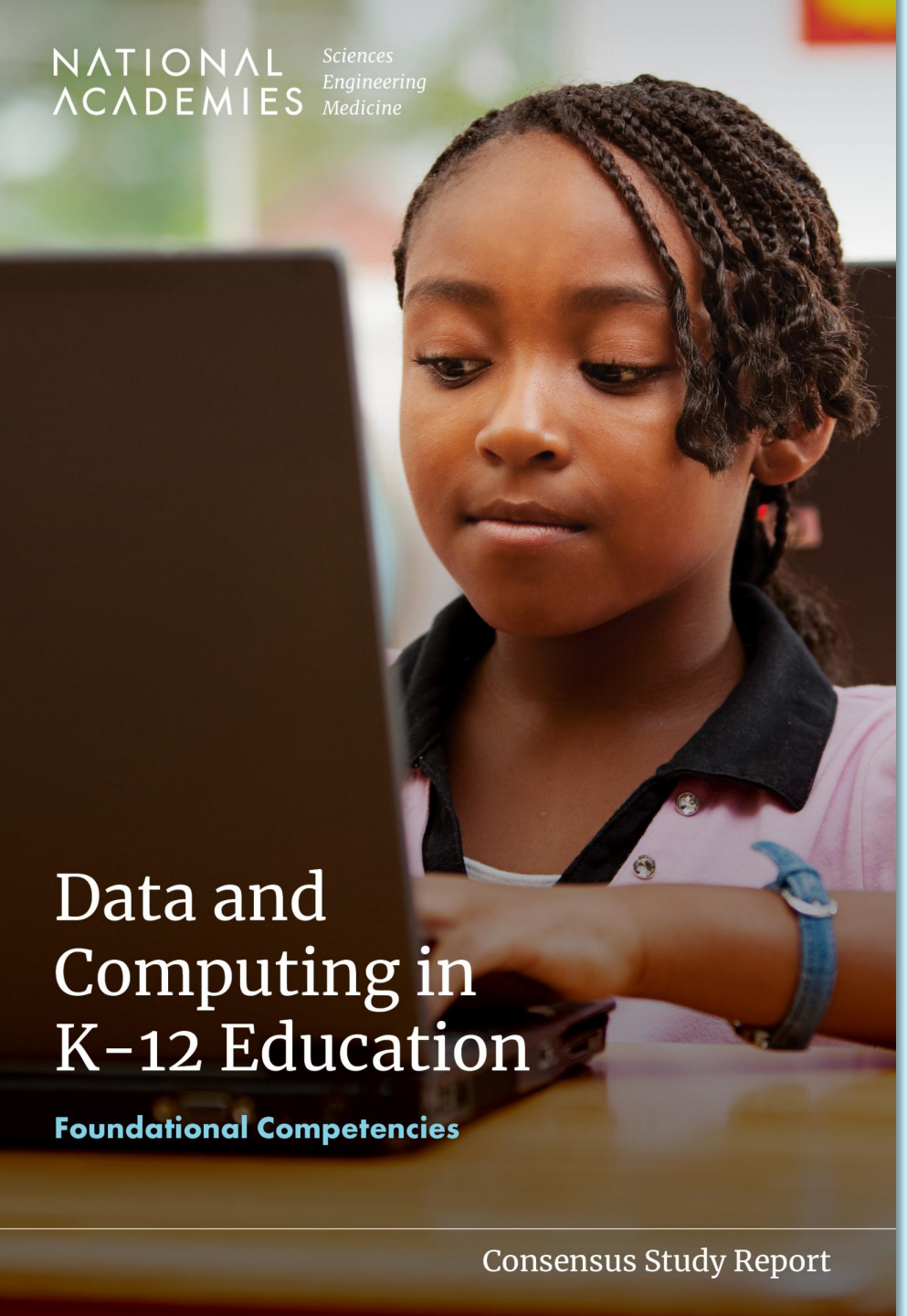
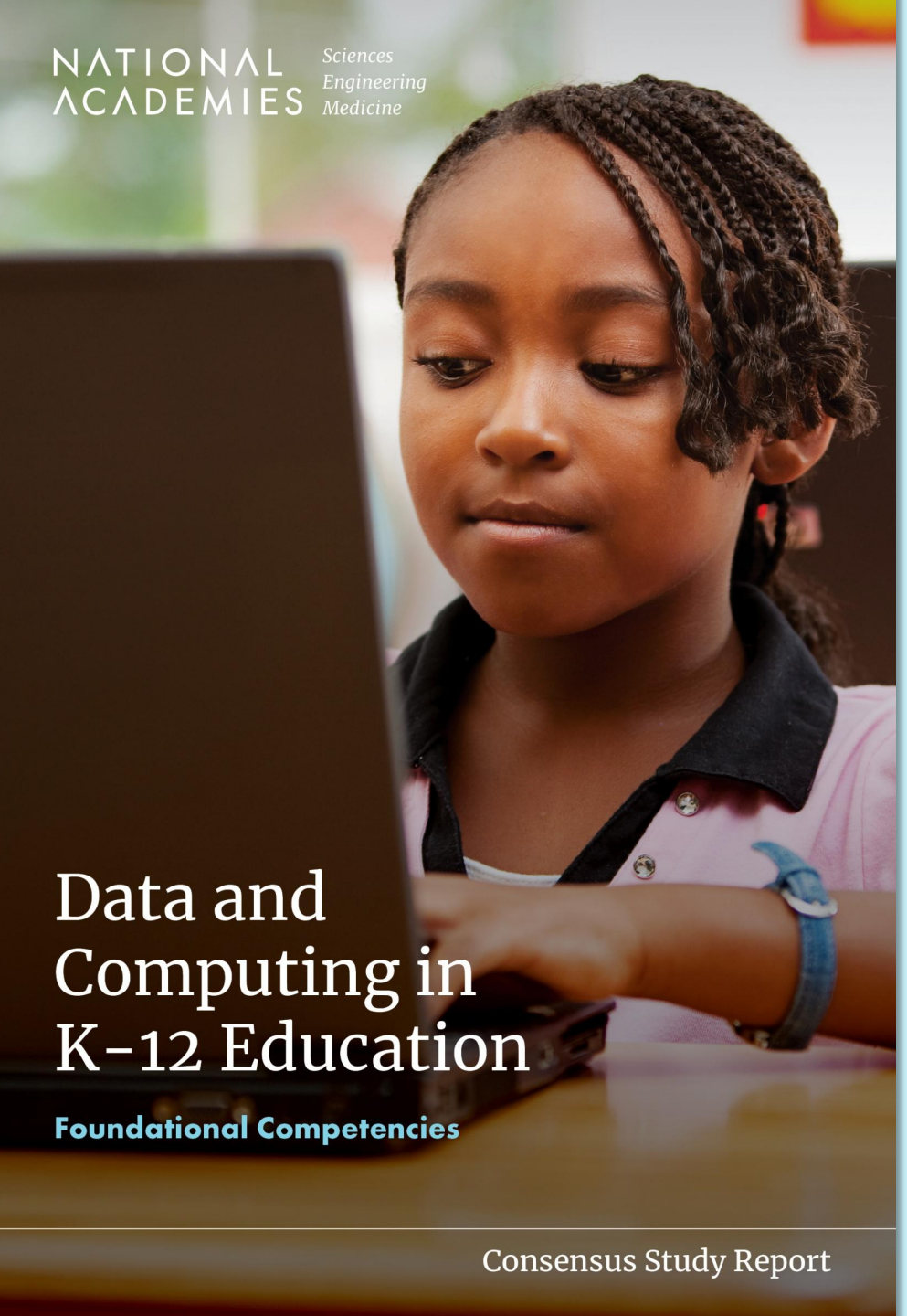


FIGURE 3-1 Data investigation process cycle.
SOURCE: Mojica et al. (2021).



Thank you to our sponsor

National Science Foundation



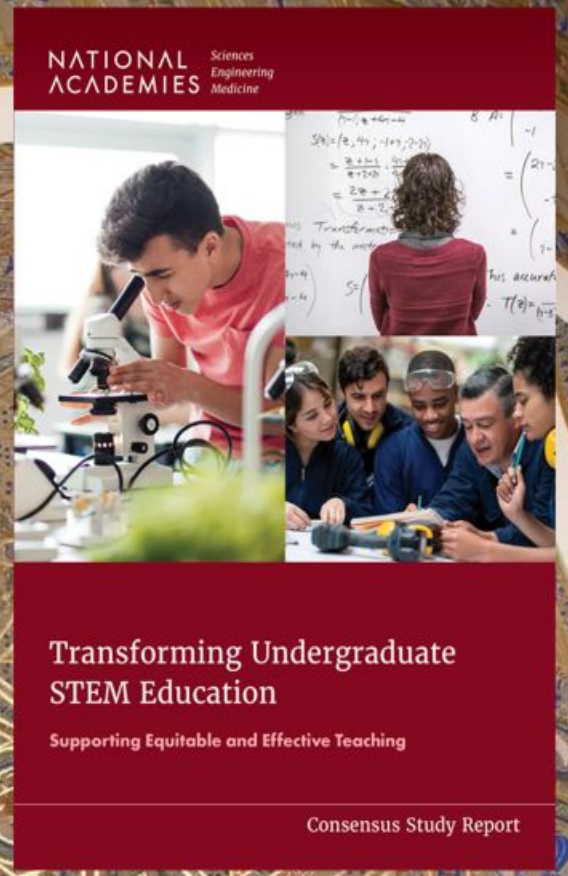
Thanks for listening!

Download the report for free

nationalacademies.org/data-computing-ed

NATIONAL ACADEMIES Sciences Engineering Medicine

Transforming Undergraduate STEM Education: Supporting Equitable and Effective Teaching



- **Toward Equitable and Effective Learning Environments**
- **Valuing and Supporting Instructors**
- **Measuring and Advancing System Change**

https://nationalacademies.org/UG-STEM-Teaching