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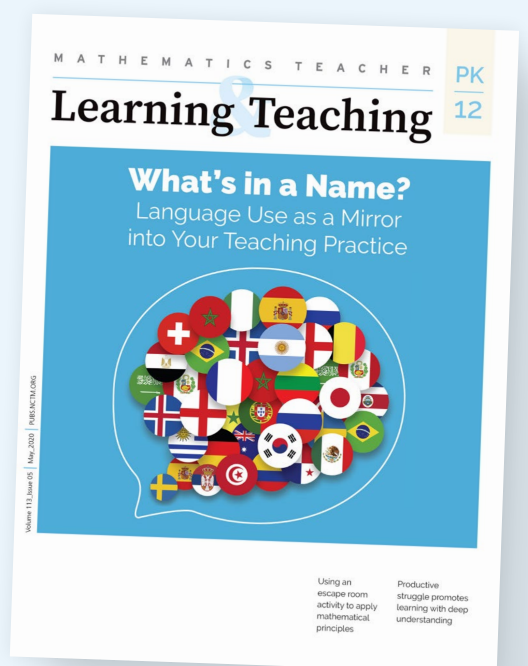


NATIONAL COUNCIL OF TEACHERS OF MATHEMATICS

Making Sense of a Data-Filled World

Jo Boaler, Tanya LaMar, and Cathy Williams

I (JB) received a message recently that piqued my curiosity—Steve Levitt, a University of Chicago economist, famous for his book *Freakonomics*, wanted to talk with me. Because my contacts usually come from the world of mathematics and education, I wondered what it was that Steve wanted to discuss. What I did not know at the time was that phone call would be the start of one of the most exciting new initiatives I have encountered in my work in education, which has the potential to significantly change the mathematics we teach in classrooms. Steve became interested in changing the mathematics taught in schools from helping his own children with their mathematics homework. As a professional economist using mathematics in his own work, Steve immediately noticed the antiquated nature of the high school content and the gap between the mathematics his children were learning and the mathematics he was using in his own work. Steve and his center at the University of Chicago asked the visitors to their Freakonomics website—professionals from across the globe—what mathematics they used in their work; the results are shown in figure 1.

The respondents to the freakonomics survey were mostly male professionals (and specifically those who visit the freakonomics site), so we also administered the survey to a different group of professionals. Figure 1 also shows the results from 427 education leaders (mostly female) from the Curriculum and Instruction Steering Committee (CISC). The two samples were purposeful, and not random, but the similarity between the results is striking, showing that most of the professionals sampled did not believe that they used much of the mathematics they learned in school, but they were aware of their use of data knowledge and tools.

During the next 18 months, our teams at the University of Chicago and Stanford University joined with other leaders across the United States and world to consider the issue carefully (see, e.g., https://ed.stanford.edu/news/bringing-math-class-data-age). It quickly became clear that all students—starting from the youngest in prekindergarten to those in college—need to learn the mathematics that will help them develop data literacy, to make sense of the data-filled world in which we all live. In this article, we

At youcubed, we believe that helping students become data literate is a moral imperative for teachers.

explain the importance of our new initiative, note the reasons it is so exciting for all teachers and students, and share some important resources for teaching with a data perspective across PK–12.

DATA SCIENCE FOR 21ST CENTURY LIVING

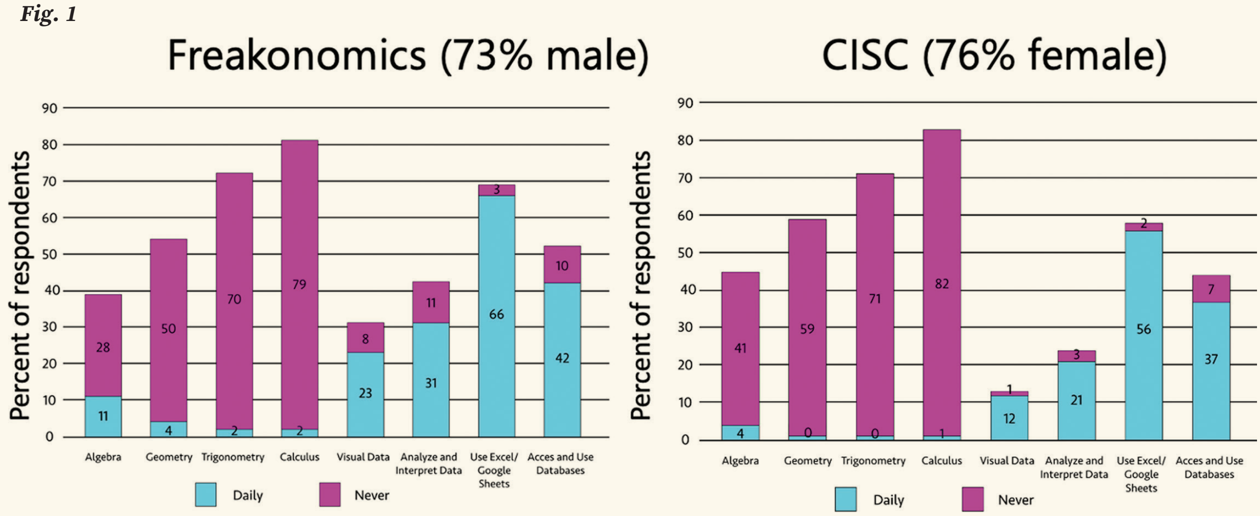
Every day, humans generate data simply by existing. The amount of data in the world is so large that in 2020, there were 10 times as many data points as stars in the universe (Messy Data Coalition 2020). Often referred to as the data revolution (Wolfram 2020), this constant production and recording of data has changed the way the world works; and whatever job your students go into, they will be making sense of data. The demand for qualified data scientists continues to skyrocket; in LinkedIn's 2020 jobs report, data scientist was among the top 15 fastest growing jobs in 16 of the 17 countries included in the report (LinkedIn 2019). Data awareness and data literacy are needed to not only be an effective employee but also function in the modern world. We must make sure that even our youngest students are given opportunities to understand data and data visualizations. If we do not help students become data literate, they will be left vulnerable to people who are misrepresenting issues and data. Unfortunately, previous research has shown that students are not well prepared to be vital consumers of data and online resources (Wineburg and McGrew 2016), which has led to concerns among many for a threat to truth and democracy. Our new data science PK–12 initiative is designed to counter this threat and offer resources for teachers that they can use to excite their students about data in the world.

WHAT IS A DATA LITERACY PERSPECTIVE?

At youcubed, we believe that helping students become data literate and able to read their data-filled world is a moral imperative for teachers. The Common Core State Standards for Mathematics (NGA Center and CCSSO 2010) took a step in the right direction with respect to data literacy; however, more can be done, and many states are working to enhance this with new initiatives focused on data science. Revisions of the standards will probably pay greater attention to this important area, and new frameworks such as the California Mathematics Framework 2021 highlight the ways the content of the Common Core can be oriented toward data literacy.

To help develop data literacy, our team at youcubed has drawn from the pedagogical practice of a *number talk*, a short routine in which students discuss the different ways they can see and solve number problems, in proposing a similar practice called a *data talk*. In a recent issue of *MTLT*, Campbell (2020) extended the idea of a number talk to that of a *representation talk* during which students notice and wonder about several mathematical representations, including geometric figures and graphs. Our "data talks" follow a similar approach and build on an initiative that came from *The New York Times* and the American Statistical Association. *The New York Times* provides readers with a weekly data representation to investigate and discuss, but most representations require levels of mathematics and data literacy appropriate for middle school and upwards. Our data talks initiative is purposeful about including data representations that are engaging and

Fig. 1



These graphs show data collected from visitors to the Freakonomics website (n = 913) and CISC members (n = 427), as well as the two most commonly answered responses of "Daily" and "Never."

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accessible for all ages of students, including transitional kindergartners. We launched our data talks section of youcubed.org toward the end of 2020, and it quickly became popular with teachers and students across the PK–12 range.

The aim of a data talk is to show students a data representation and ask them, "What do you notice?" and "What do you wonder?" Giving students the time to study the data visualization, discussing what they are seeing, and working to make sense of the story being told through the data are important. As Alberto Cairo mentions in his book *How Charts Lie: Getting Smarter about Visual Information* (2019), "We need to get used to perusing them with attention and care. Instead of just *looking* at charts, as if they were mere illustrations, we must learn to read them and *interpret* them correctly" (p. xii). After students have discussed the key areas of the data visualization, teachers can lead a discussion with students, inviting them to connect the story to their own interests. See figure 2 as an example data talk.

Teachers do not need to be experts in the content of the data representation; in fact, modeling for students that teachers do not have all the answers is beneficial—that instead, we have questions and curiosity. Data talks are designed to be engaging for students, with contexts such as basketball, endangered species, and popular dogs, and to encourage students to think about variables, the use of axes, the meaning of data, questions of data ethics, and other important components of data literacy, as students learn to *read* data representations accurately. Data talks are an ideal start to lessons—whether online or in person. An example of a data talk enacted with a group of middle school students can be seen here: https://www.youcubed.org/resources/what-do-you-notice-what-do-you-wonder/.

Boaler's new online course titled 21st Century Teaching and Learning: Data Science introduces PK–12 teachers to data literacy and data science, with a range of teaching ideas sharing that data science draws from content that extends across different subject areas, including the humanities. An important part of data science is the practice of asking questions and communicating findings about explorations. Ideally, students will come up with questions about which they are curious and conduct data investigations, integrating mathematical thinking with literacy, as well as the content of the investigation, which could be about science, the arts, or any other area. All subjects can take a data perspective—in history, we use data to understand events from the past. Physical education classes can include students collecting data on their fitness. Science is filled with opportunities to learn from data, considering our climate, our health, and a myriad of other important topics. Our minds are built for seeking patterns and making sense of the world around us. Data organization through visualizations is an engaging and useful way for making sense through patterns. For PK–5 teachers who teach multiple subjects, a data investigation can achieve standards from several subjects in one activity. As students work with data, they will be learning important mathematical ways of thinking that will help them, not only in school but also in the world.

As an example of the ways a data perspective can infuse all your teaching, one of the activities from the *Mindset Mathematics: Visualizing and Investigating Big Ideas, Grade 1* (Boaler, Munson, and Williams 2021) asks students to measure classroom objects using Cuisenaire® Rods and organize their data (see figure 3). Students can make charts and learn the important practice of organization. This gives students opportunities to learn *systems thinking*, which is the ability to "zoom out" and notice patterns, cycles, and structures across a system—in this example, across a data system (McNamara 2006). When we are teaching students of all ages, we have often found that students observe patterns well and have intuitions about the ways that details of one record should be kept together in their recordings, but they often lack understanding of ways to systematically organize and keep track of their thinking. For example, if students are collecting data about their peers, each row in their table could represent an individual student, and each column may represent a different attribute that is collected about each student. Activities that encourage data collection and organization will help students with this important aspect of data literacy.

DATA LITERACY IN THE COMMON CORE

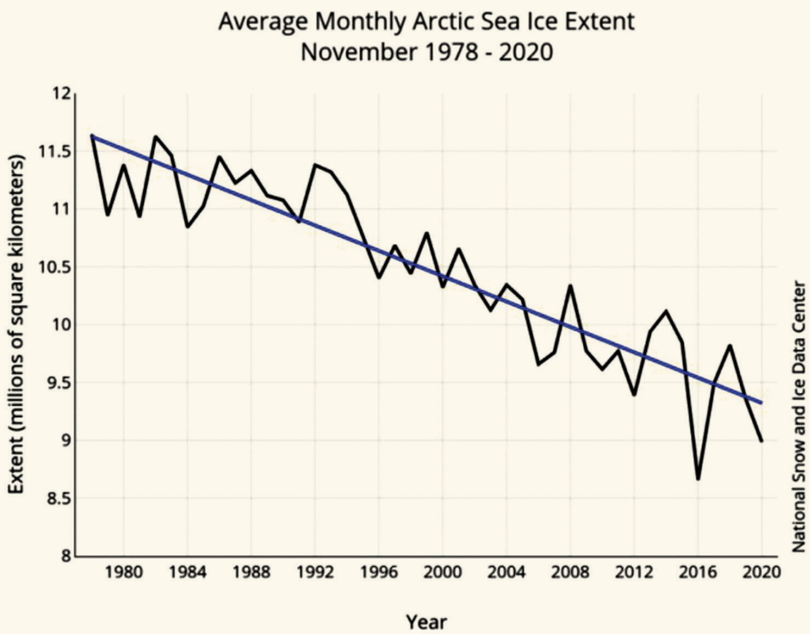
Traditionally, the consideration of multiple variables has been reserved for older children; however, many educators agree that children as young as transitional kindergarten can consider multiple variables as these types of comparisons arise naturally. At the prekindergarten level, children can gather and compare toys by their size, color, or feel (squishy vs. hard). In kindergarten, teachers can help students with collecting, sorting, and classifying objects on the basis of either qualitative (e.g., color) or quantitative (e.g., size) measures—all of which are real data. For example, students can be given buttons and encouraged to ask questions about them, leading to the sorting of buttons into groups where students have chosen their own variables. In figure 4, from *Mindset Mathematics: Visualizing and Investigating Big Ideas, Grade K* (Boaler, Munson, and Williams 2020), students have chosen to sort buttons using the variables of (1) big buttons, (2) red buttons, (3) buttons that are little and green, (4) blue buttons, (5) transparent buttons, and (6) buttons that are not flat and are little.

In grade 1, teachers can extend the work to include more categories or variables, larger sets, and summarizing patterns. In grade 2, data representations such as line plots and bar graphs are included in the standards, though we have found that younger students can

Fig. 2

Melting Arctic Ice

What do you notice?
What do you wonder?
What is going on in this data visualization?

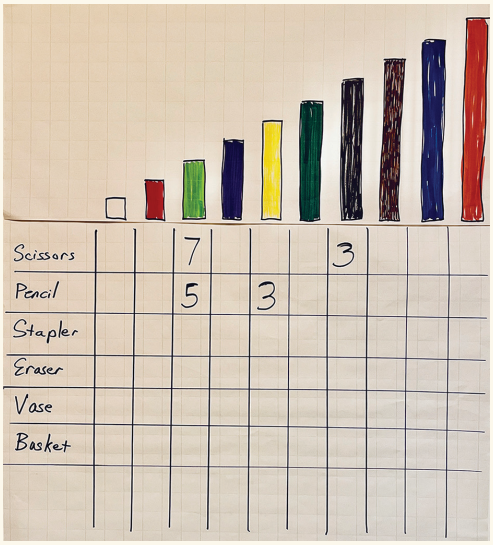


Some extra information given:

This graph from the National Snow & Ice Data Center shows the extent of sea ice in the month of November between 1978 and 2020. What do you notice about this trend? Why do you think this trend is happening? *The New York Times* released an article saying that some populations of polar bears have declined by 40% between 2000 and 2010. Polar bears live on sea ice. Do you think this graph is related to the decreasing polar bear population?

This Melting Arctic Ice data talk from youcubed.org shows the measures of average monthly arctic sea ice from 1978 to 2020. The aforementioned graph is courtesy of the National Snow and Ice Data Center, University of Colorado, Boulder.

Fig. 3



Students measure classroom objects with Cuisenaire® Rods and record how many objects they see of different sizes.

engage with many different data representations and create their own. For example, students can ask questions that result in collecting and sorting sets of leaves or sea shells. The important components of these activities is for students to ask their own questions, determine the variables or attributes they will investigate, communicate why they have chosen them, and share their results, convincing others of the patterns they find. Such activities are rich in the Standards for Mathematical Practice (SMP; NGA Center and CCSSO 2010). Students make sense of problems (SMP 1), reason abstractly (SMP 2), construct viable arguments (SMP 3), model (SMP 4), and look for structure (SMP 7). Grade 2 students can continue to make sense of multivariate data and use it to make comparisons. For example, students can measure plant growth by recording height measurement of several plants over time and making comparisons or noticing trends in growth. In grade 3, students can continue to learn ways to ask questions that lead to data collection and analysis and design data studies that allow them to answer their questions. For

Fig. 4

In this Button Sorting activity (Boaler, Munson, and Williams 2020), students sorted buttons using the variables of (1) big buttons, (2) red buttons, (3) buttons that are little and green, (4) blue buttons, (5) transparent buttons, and (6) buttons that are not flat and are little.

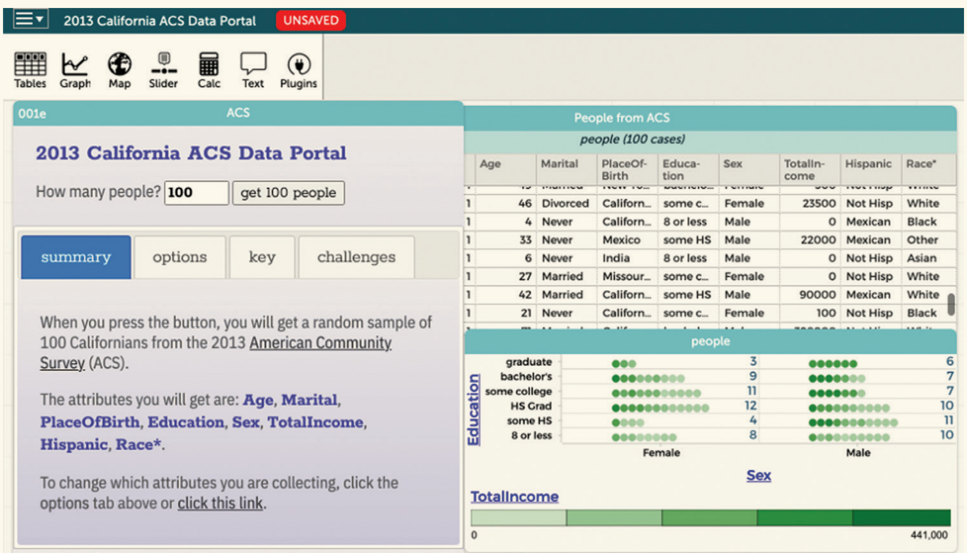
example, students can compare plane figures by number of sides, perimeter, and area. In grades 4 and 5, students can collect data that include fractional units, providing important opportunities to use fractions in real situations. Importantly, all these activities integrate data content with a range of mathematical practices.

From grade 6, the Common Core State Standards bring in considerable focus on statistical methods, which are useful in analyzing real data sets. We use the term *real data sets* to emphasize that students should be working with real data rather than data contrived to match particular contexts or content. One of the greatest powers of data science is its connection to real situations and problems; it is vital that this connection is maintained as students engage with the material. We never want students to feel as though they are working with made-up or inauthentic data because this has the potential of disempowering their learning. In grade 6, students should be asked to look at the visual representations of different data sets with understanding of the situation, investigating with measures of center and variability. They can also consider which of the three measures of center is most appropriate to use to summarize and communicate about the data. In grade 7, students are introduced to sampling and questions of fair samples, and they start to develop probability models that are taken further in grade 8. In these middle grades, students can start to become vital consumers of data, asking questions such as, "Is this a fair and clear way to represent the data?" Students can also learn to deal with uncertainty in data collection, analysis, and representation and reflect on how their decisions in each of these steps have the potential to introduce bias.

For example, students can work with the California American Community Survey (ACS) data using the Common Online Data Analysis Platform (CODAP). Students can select a random sample from the data set, explore the data using visualizations, and look for patterns in the data. Figure 5 shows an example of student work. The student has used CODAP to select a random sample of 100 participant responses from the data set; has visualized the data by gender, education level, and income; and sees a pattern that in this sample, males tend to have higher total income measures than females. Next, students can share their findings and engage in a discussion addressing such questions as "Is this sample representative of all Californians?" or "What could be some other reasons that women in this sample seem to have lower total incomes compared with men?" and "Why does this visual data display information about only 98 participants when we know our sample contains 100?"

This focus on data representations as well as statistical and probabilistic modeling should extend into high school, though it is often lost when schools

Fig. 5



Sample student work shows investigation of data from a sample of 100 participants in the California ACS.

focus exclusively on algebra and geometry. Integrated approaches to high school content are ideal, and curriculum that truly integrates mathematical ideas, such as Core Plus and IMP, present data investigations that give students meaningful opportunities to plot graphs with linear, quadratic, or exponential functions, for example, and interpret them—bringing algebra to life with a data perspective. Activities that are focused on social justice (see Berry et al. 2020; Gutstein 2007) present examples of engaging data explorations that combine data with the content of algebra and geometry. In the high school grades, working with data also provides opportunities for learning 21st-century skills like coding, and tools like spreadsheets, modeling programs, and data analysis packages (e.g., Desmos, Geogebra, and CODAP), as well as drawing from all eight Standards for Mathematical Practice (NGA Center and CCSSO 2010).

A MORE EQUITABLE FUTURE

For generations, high schools in the United States have focused on one course as the ultimate, college attractive, and high-level course—calculus. This has led to a heavy focus on algebraic content in the earlier years even though a tiny proportion of students in the school system take calculus (Daro and Asturias 2019). When students do take calculus, it is often taken after rushing through years of content without the development of deep understanding. Research shows that most students who take calculus in high school repeat it in college or take a lower-level course afterward (Bressoud 2017). Data science and statistics offer a new and exciting alternative to calculus—and research suggests that the content of such a pathway is much more engaging for broader groups of students, providing more equitable participation in higher-level courses (Boaler, Cordero, and Dieckmann 2019). In California, the University of California and California State Universities recently issued a statement to high schools across the country stating that data science is a valued course that could be taken instead of, or in addition to algebra 2 (University of California 2020). Many states are now recognizing that students have taken sufficient algebra by the end of algebra 1, and at that point could be given choices of different pathways—one could lead to calculus, others could lead to data science and statistics, and others may also be developed. The provision of new pathways, which focus on 21st-century mathematics content, such as data science, is an exciting new development for the United States and is currently being enacted across multiple states (Dana Center 2020).

One serious problem with the calculus pathway is the fact that so many prerequisite courses are required by most districts that students need to be "advanced" in middle school to reach calculus by grade 12. This has resulted in middle schools compressing important content for some students, whereas others are filtered out of the calculus pathway—often as early as grade 6. Data science, by contrast, can be offered as a third- or fourth-year high school course with no prerequisites and no need for advancement in middle school (see, e.g., https://www.youcubed.org/resources/high-school-data-science-course/). This, we believe, will open the doors of a science, technology, engineering, and mathematics (STEM) future to many more students and to a more demographically diverse group of students. Mathematics has been communicated, over the years, as an exclusive subject, for only some people. Data science, by contrast, is being communicated as a subject in which anyone can excel. Data science would not and should not be offered as a lower-level pathway—the mathematics of data science, including matrices, linear algebra, and probability, constitute a rich and important area of mathematics, and is important for a multitude of college courses.

In addition to the opening of STEM pathways with a high-level mathematical course that does not require middle school advancement, data science will offer more equitable outcomes because the nature of the work—investigating real situations, instead of manipulating algebraic expressions—will appeal to a more diverse group of students, bringing more girls and students of color into STEM work (Boaler, Cordero, and Dieckmann 2019). The ability to read, analyze, communicate, and make sense of data will continue to gain power and influence in the 21st-century, and the people who have the ability to wield the power of data science will be those whose decisions affect people's lives across the world. Having a more diverse group of data science learners means a more diverse team of leaders and decision makers—which is important for the world. Teaching students to be data literate and to develop an interest in data science is an important goal for all teachers; it empowers learners with 21st-century mathematical tools, and it lays the groundwork for a more equitable future, with classrooms that no longer include the question: "When am I ever going to use this?"

SUMMARY OF RECOMMENDATIONS

- Be excited about data—a simple shift in how often, and in what ways we talk about data in our classrooms can open the floor to invite students' mathematical thinking and curiosity.
- Use real data in classroom examples—integrating data that is relevant to students' lives provides opportunities to develop data literacy and show students how mathematics applies to the real world.
- Take an online course to learn teaching ideas as well as develop knowledge in data analysis (e.g., www.youcubed.org/21st-century-teaching-and-learning/).
- Conduct data investigations—collecting, analyzing, and communicating about data give students opportunities to deal with uncertainty in data, to pursue their own lines of thinking, and to connect mathematics to their own lives.
- Implement data talks (https://www.youcubed.org/resource/data-talks/) as a classroom routine—developing data literacy will be an ongoing learning goal for our students; regularly providing moments to be curious about data will build this skill and also invite student voice into mathematical discussions.
- High school teachers, teach a data science course at your school (e.g., Youcubed's Explorations in Data Science). It takes just one teacher at a high school to offer a data science course and open this crucial pathway opportunity for students.
- Curriculum supervisors and administrators, advocate for a high school pathway in data science and support teachers in building this new option for students.

Recommended Resources

- Join the data science movement: www.youcubed.org/sign-up/ and https://messydata.org/.
- Learn the ideas of data science for PK–12 teachers: new online course.
- What is data science? Why is it important?
    - News articles and films: https://www.youcubed.org/resource/data-literacy/.
    - Videos to share with parents and others: Stanford Press Release, Women in Data Science.
- Data talks: resources and examples.
- Integrate data science in your classroom tomorrow: grades 6–10 lessons.
- Youcubed's HS data science curriculum.
- Concord Consortium's codap.
- Data Science big ideas K–12.

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