THANKS TO THE DEVELOPMENT AND DEPLOYMENT OF FEDERALLY FUNDED SATELLITE-, BUOY-, AND AIRCRAFT-BASED REMOTE SENSING INSTRUMENTS, CONTINUOUS STREAMS OF EARTH AND SPACE DATA ARE PUBLICLY AVAILABLE VIA ONLINE DATABASES. THIS ACCESSIBILITY PROVIDES FLEXIBILITY TO Explore GEOSCIENCE DATA THAT ARE INTERESTING AND RELEVANT TO STUDENTS—KEystone COMPONENTS OF THE NEXT GENERATION SCIENCE STANDARDS (Achieve 2013a). In this article, I outline activities that leverage archived geoscience data, and describe design considerations for a new 11th-grade interdisciplinary science course that draw on education research and practice. Through pairing of design considerations and application in the context of an urban under-resourced technical high school, I illustrate ways geoscience databases can be used to realize NGSS vision, as well as expand possibilities.

CONFRONTING CHALLENGES
Typical high school science courses include opportunities for students to collect data through their own investigations for subsequent analyses. Direct experience in data collection may help evoke students’ consideration of data uncertainty and interest (Osborne et al. 2003; Kanari and Millar 2004). Firsthand data activities are common in today’s high school science classrooms; however, due to the structure of American K–12 public education, investigation resources are not evenly distributed. This may preclude students’ and teachers’ access to materials and tools used in popular high school investigations.

New science domain content and expectations, coupled with associated changes in state graduation requirements, can amplify the disparity of science department resources. I experienced this inequity while designing activities to support newly adopted science standards and the corresponding shift from two to three years of required high school science. Without access to a gas-equipped laboratory, sensors, and variety of chemicals, I searched the internet for feasible firsthand data activities for NGSS HS-PS1-5 (Table 1; see Online Connections) (Next-GenScience 2020), prioritizing products of science education organizations and agency-funded studies.
Implementing new high school science expectations

Building on students’ prior exploration of NGSS MS-PS1-4 and associated atomic-molecular theory activities (Michaels, Shouse, and Schweingruber 2008), I kicked off a sequence of firsthand data activities by prompting students to record and make sense of their observations of a popular chemistry demonstration—the iodine clock reaction (TheAzmanam 2016). Teams of three to four students gathered around large tables and replayed the video demonstration on a shared laptop computer. As team members exchanged thoughtful observations and initial ideas about what most likely caused the liquids to change color at different times, I circulated from team to team as students collaboratively synthesized their observations and initial explanations. I teach in a technical high school and am mindful of the assets students bring to sense-making, so I encouraged students to leverage the knowledge they had acquired in career preparation classes and outside-of-school experiences.

Students displayed their illustrated syntheses of team ideas on 24 x 32-inch whiteboards (MacIsaac 2002; Noschese 2010) throughout the classroom. The seven teams shared their emerging work, with one team member available to field questions and receive feedback—similar to poster sessions at professional scientific meetings. After students reported back to their team, the poster session concluded with a whole-class discussion. Students noticed that the volume of all the liquids appeared to be the same. Students who are studying hairdressing related their explanations to hair-color preparations, and suggested that the concentration of substances in one of the combined liquids may be different. Using the language of their field, hairdressing students noted the critical role of the “volume” (concentration) of “developer” (reactants) in how quickly and intensely the hair will be “processed.” A shared summary of these ideas and insights served as a valuable resource for the subsequent sequence of firsthand data activities in which students used an online simulation (ACS 2020).

Through using an online simulation (ACS 2020), students were able to adjust the concentration of reactants in order to explore the effect of concentration on chemical reactions over time (Figure 1). As students made sense of how the simulation related to the iodine clock reaction, I circulated from team to team, probing their thinking with questions that pivoted around the HS-PS1-5 crosscutting concept of patterns (Figure 2). Highlighting the standard’s science and engineering practice of constructing explanations, each team offered explanations based on qualitative evidence from the simulation (relative steepness of slope), quantitative evidence (number of reactions within same time period), as well as classmates’ career insights (e.g., relationship between hair “processing” rate and the “volume” (concentration) of “developer” (reactants). Team explanations and informative illustrations centered on what had been highlighted in the simulation activity—that a higher
concentration of reactants increases the likelihood that reactants would collide within a period of time. In this way the activity supported the HS-PS1-5’s disciplinary core idea of chemical reactions (Table 1; see Online Connections), while bringing to mind the significant role of collisions in chemical reactions.

The significance of collisions in the simulated chemical reactions elicited students’ previous sensemaking activities, in which a connection between temperature and atomic/molecular movement had been developed (Michaels, Shouse, and Schweingruber 2008). Facilitated by my guiding questions (Figure 2), teams reflected on the relationship between collisions, temperature, and kinetic energy in order to make sense of the role of collisions in chemical reactions. Looking to validate and extend students’ thinking, I encouraged students to record qualitative observations as I demonstrated the impact of concentration and temperature on the reaction rate of calcium chloride (road salt) and sodium bicarbonate (baking soda) solutions (Kessler 2013).

This activity complemented individual observations made and shared as teams returned to the online simulation to explore the effect of temperature on the reactants within the same TABLE 2

<table>
<thead>
<tr>
<th>NGSS HS Performance Expectation</th>
<th>Geoscience Database</th>
<th>Relevant Education Resources</th>
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<td>HS-ESS3-4 Earth and Human Activity</td>
<td>Clean Air Status and Trends Network (CASTNET) (EPA 2020d)</td>
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<td>AURA (NASA 2020d)</td>
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<td>HS-ESS3-5 Earth and Human Activity</td>
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<td>HS-ESS1-3 Earth’s Place in the Universe</td>
<td>Data access for SDSS D12 overview (SDSS 2020a)</td>
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<td>HS-ESS2-2 Earth’s Systems</td>
<td>Available groundwater recharge data (USGS 2020a)</td>
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<tr>
<td></td>
<td>Earth data (NASA 2020b)</td>
<td>The water cycle: Heating the ocean (NASA 2020c)</td>
</tr>
</tbody>
</table>

FIGURE 2

Sample prompts for firsthand data activities, leveraging the crosscutting concept of patterns.


• What **patterns** did you observe in the simulation?
• How may the concentration of reactants help explain the chemical reaction **pattern** you observed?
• How may the temperature help explain the chemical reaction rate **pattern** you observed?
• You have qualitatively communicated the chemical reaction rate patterns. What steps can you take to quantifiably communicate the **patterns** you observed?
• What are some ways you can communicate the chemical reaction rate **patterns** you observed to others?
period of time. As before, I shifted from team to team to listen, observe, and prompt students’ thinking, using HS-PS1-5’s crosscutting concept of patterns as a lever (Figure 2), students collaboratively constructed understanding towards the targeted disciplinary core idea. Applying professional learning experiences in Modeling Instruction (Jackson, Dukerich, and Hestenes 2008), I challenged the teams to identify a way to quantify the relationship between the two variables using data from the simulation. This provided an opportunity for students to creatively practice another aspect of the targeted HS-PS1-5 science and engineering practice—to “make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables” (Achieve 2013b).

I asked students to modify their explanations about the iodine clock reaction in order to integrate new data and insights. The revised whiteboards included algebraic models, graphs, illustrations, and text, providing rich resources for discussion and a variety of ways for team members to contribute (Jackson,

**FIGURE 3**

Sample students’ models and evidence-based claims for NGSS HS-PS1-5 firsthand data activities.

We tested to see if the temperature affects the reaction rate of two chemicals in a simulated solution, and concluded that there is a correlation between temperature and chemical reaction rate. The simulated chemicals are called A and B; A and B react to produce C, a molecule made of A and B. When we timed the chemical reactions at three different temperatures, we found that at the lowest temperature only two molecules were produced, but at the highest temperature, all of A and B reacted to produce five products in half the time of the in-between temperature. Another piece of evidence is the slope of the trend line for products versus time gets steeper as the temperature increases. The slope for all tested temperatures was positive, so the higher the temperature, the more product was produced by two chemicals bonding. The slope of the highest temperature solution shows a reaction rate of around two products per second. The slope of the middle temperature shows a reaction rate of one product per second, and the slope of the lowest temperature has a reaction rate of around 0.5 product per second. The reason for the different reaction rates is that the temperature of the solutions means the chemicals move at different speeds; when they move more, they are likely to collide and have energy to bond together. There is more energy in the highest-temperature solution for the chemicals to collide and bond.
Dukerich, and Hestenes (2008). In addition to team whiteboard efforts, I asked students to individually summarize their explanations in a short paragraph. This facilitated my assessment of individual student progress, as well as the range of evidence students offered. Explanations included quantitative claims as to the independent and combined effects of temperature and concentration on chemical reaction rate (Figure 3).

Once I was assured that all students were prepared to contribute insights and evidence, we organized a new poster session. I asked students to record at least one way each team’s efforts contributed to their understanding—whether it be a well-organized whiteboard or unique content—via small sticky notes. In this way I looked to foster a class community culture that values diverse contributions and positions students’ products as primary resources for new knowledge construction. At the conclusion of the poster session, we held a whole-class discussion during which team whiteboards and sticky notes were used as reference. This exchange resulted in the construction of a more compelling, shared explanation for the iodine clock reaction demonstration.

The synthesized explanation, which included citations of team contributions, reflected many of the features listed in the HS-PS1-5 performance expectation and associated disciplinary core idea (Table 1; see Online Connections). In an effort to mirror the state NGSS assessment, the sequence of firsthand data activities ended with a summative assessment based on the state’s science assessment item cluster design template and high school item cluster specifications (Kelly 2019a; Connecticut State Department of Education 2019). Consequently, I was
able to demonstrate that the new 11th-grade science activities aligned with the state’s science expectations for high school students (National Research Council 1999).

Locating secondhand data
While firsthand data activities are valuable, classroom experience and research suggest that access to a range of data types gives students opportunities to apply a greater number of scientific practices (Hug and McNeill 2008) and facilitates the development of a deeper understanding of the investigated phenomenon (Duschl 1990). Locating secondhand data—data that had been collected by others and are associated with the same, or similar, phenomenon—can significantly widen the range of data types. Sources of secondhand data include data collected by other students, as well as data that are too time-consuming, expensive, or dangerous for students to collect themselves (Magnuson et al. 2004). Although more commonly used by the science research community, geoscience databases (Table 2) provide publicly available secondhand data that are large in quantity and types of data. For the purposes of high school science departments that are chronically under-resourced, these databases can serve as lifelines to equitable access to grade-level sensemaking opportunities that extend beyond baseline performance expectations.

Mining standard-relevant geoscience data
As I considered ways data sets in geoscience databases are the same or similar to the HS-PS1-5 firsthand data activities, I recalled learning that the air temperature and concentration of reactants in the lower atmosphere affects the production of ground-level ozone (Department of Geosciences, SUNY/Stony Brook 2009). Ozone—a molecule composed of three oxygen atoms—is a naturally-occurring component of Earth’s lower and upper atmosphere. Near the Earth’s surface, ozone is produced...
when naturally occurring, volatile organic compounds—the compounds that are responsible for the scent of trees and meadows—react with other natural components of the lower atmosphere (e.g., nitrogen oxides) (Fischetti 2014).

This reaction requires energy input from ultraviolet sunlight (NASA 2003) and will occur at a higher rate when atmospheric components are moving faster (as measured by temperature). Production of ground-level ozone can be increased when there is a higher concentration of volatile organic compounds in the lower atmosphere, largely through organic matter use (e.g., combustion of wood, coal, oil, gasoline) and manufacture (e.g., production of plastic, paint, cleaning solvents). High ozone concentrations in the lower atmosphere are associated with unhealthy air quality that can negatively impact the respiratory function of terrestrial plants and animals. Since ground-level ozone can be dispersed via wind, meteorological and topographic characteristics of a location can influence the frequency and severity of poor air quality events (Fiore and Clifton 2016; EPA 2020a; EPA 2020b).

Air quality is categorized and coded as part of the Environmental Protection Agency’s national daily reporting system in order to warn residents about unhealthy outdoor air quality conditions. I was able to locate a database for daily maximum ground-level ozone, measured as concentration (parts per billion) within an eight-hour period (CT-DEEP 2020) for stations that represent rural, suburban, urban, coastal, and inland locations across the state (Figure 4). Data tables representing many months and years for numerous stations are color-coded by a category of condition, providing a ready-made visual model for students to make observations and identify patterns (Figure 5). Archived records of daily air temperature data for numerous geographically described locations (elevation, latitude, longitude) across the nation are accessible through a National Oceanic and Atmospheric Administration (NOAA) database (Figure 6) (NOAA 2020a). Both of these geoscience databases are valuable resources for students to design individual investigations about the relationship between air temperature and ground-level ozone concentration for a wide range of locations and time periods.

**Leveraging secondhand data**

I presented to students a collection of artifacts associated with the state’s air quality, such as state newspaper articles (Shay 2019) and images of daily air quality alerts in local weather reports and schools (AirNow 2020) to give some background information in formats that community residents typically encounter. Highlighting the relationship between high air temperature and high ground-level ozone concentration, the curated collection served as a bridge between the firsthand data and secondhand data activities. I also provided sample data sets that suggested an obvious pattern between high ozone concentration and high air temperature that occurred in 2017 during the month of May (Figures 5 and 6), as well as informative text about ozone formation (EPA 2020). I reviewed the type (e.g., ground-level ozone concentration, maximum daily air temperature), range (e.g., geographic location, time), and origin (e.g., EPA, NOAA) of data resources in effort to sustain orientation toward the HS-PS1-5 standard.

After analyzing May 2017 ozone and air temperature data for the school’s location, I asked each student to record and share three questions that could be explored by mining additional data from the EPA and NOAA databases. As the teams summarized and categorized classmates’ sticky note questions into common themes (e.g., effect of location on concentration of ground-level ozone, effect of season on concentration of ground-level ozone) on the class whiteboard, I helped advance students’ thinking by drawing attention to the valuable use of the crosscutting concept of patterns (Figure 7) and students’ own firsthand data findings.

### FIGURE 7

**Sample secondhand data prompts, leveraging the crosscutting concept of patterns.**

- What **patterns** did you observe in your air temperature-ozone data?
- How are the air temperature-ozone **patterns** similar during different months of the year?
- How are the air temperature-ozone **patterns** different during different months of the year?
- How are the air temperature-ozone **patterns** similar across Connecticut?
- How are the air temperature-ozone **patterns** different across Connecticut?
- How can you quantifiably communicate the **patterns** you observed?
- Given our earlier exploration of chemical reaction rates, why do these **patterns** occur?
- Using your knowledge of the locations and trade insights, what other factors may cause the **patterns**? (All students are enrolled in technical career pathways, such as mechanical engineering design and automotive.)
- What are some ways you can communicate the **patterns** you observed to others?
- What steps can you take to investigate whether factors other than air temperature may cause the observed variation in **patterns**?
Class and team discussions continued as students independently explored data, designed investigations, and communicated emerging results. I organized teams based on common investigation interests in order to facilitate efficient, meaningful sensemaking about the relationship between first- and second-hand data analyses about the impact of concentration of reactants and air temperature on reaction rates. In this way, each team could offer unique contributions to the study, much like a science research laboratory.

Students enrolled in our school’s automotive program shared information about catalytic converters and the state’s emission monitoring program, which led students to infer that since urban areas are more densely populated, more volatile organic compounds are emitted from vehicles. Students anticipated a relatively greater concentration of ground-level ozone than surrounding suburban and rural communities. One challenge for students was the need to argue their choice of familiar locations to compare, especially since the siting of NOAA and EPA stations are not fully coordinated. With many meteorological, geographical, demographic, and topographic variables to consider, students were pressed to “decide on types, how much” data were needed, eliciting the need to exercise the science and engineering practice of “planning and carrying out investigations” (Achieve 2013b) (Table 3; see Online Connections). This gave me the opportunity to share the conventional use of proxy data in environmental studies as I guided students to consider using data from stations with similar characteristics (e.g., latitude, elevation). Students were surprised to find unexpected results; for example, rural station sites can also report high concentrations of ground-level ozone (Figure 8). This prompted students to “read scientific literature” (Achieve 2013b)—freely available on agency websites—in order to identify additional variables that can affect the concentration of ground-level ozone, such as wind speed and direction (EPA 2020e) (Table 3; see Online Connections).

Likewise, teams that explored the effect of air temperature on concentration of ground-level ozone at various months and locations applied a range of science and engineering practices—particularly those that intersect with grade-level mathematics standards. Applying knowledge from the HS-PS1-5 firsthand data activities and informational text about ground-level ozone formation, as well as insights shared by students who have family members with respiratory disease, students inferred a relationship between higher air temperature and ground-
level ozone concentration. Students explored this relationship by gathering and analyzing air temperature and ground-level ozone data from different months and locations.

The crosscutting concept of patterns continued to orient students to the disciplinary core idea of chemical reactions as they constructed explanations for the observed variation in scatterplots (Figure 9). Students began to apply and expand their mathematical and computational thinking skills through a learning progression I had developed for computer-based graphical analyses and associated explanations (Table 4; see Online Connections). Practicing “mathematical and computational thinking,” students constructed “mathematical, computational, and algorithmic representations of the poor air quality phenomenon to describe and/or support claims and/or explanations” (Achieve 2013b) (Table 3; see Online Connections). Students applied rates “in the context of complicated measurement problems involving quantities with derived or compound units” (Achieve 2013b) when they described the predicted effect of a one-degree increase in air temperature on ground-level ozone concentration (parts per billion/degree Fahrenheit).

Since students had collaboratively explored firsthand data, and individually explored a range of secondhand data sets, they were able to “compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations” in their analysis and interpretations (Achieve 2013b). Evoking yet another aspect of the “analyzing and interpreting data” practice, students used “concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits)... using digital tools” (Achieve 2013b) to discern and evaluate small variations. Results and additional literature readings suggested that other variables need to be considered in order to more fully explain the variation in ozone in different locations.

**Expanding possibilities**

As promised by Hug and McNeill (2008), the processes and iteratively designed products of the secondhand data activities provided fertile pathways for students to develop, apply, and communicate a broad range of high school–level scientific practices (Table 3; see Online Connections). Unlike the firsthand data activities, the relative complexity of both the geoscience data and the investigation necessitated a deeper use of the target crosscutting concept and science and engineering practice—one that demanded high school–level mathematics (Table 4; see Online Connections). In this way, the databases helped circumvent the material and learning limitations that typically plague chronically under-resourced schools (Darling-Hammond 2000).

Policies and documents associated with the Next Generation Science Standards are based on the premise that “high academic standards help set the bar for all students, especially those typically underserved in the science classroom” (Achieve 2015). The authors of A Framework for Science Education (NASEM 2012) assert that interests and identities in the design and implementation of activities support equitable learning. While students’ identities and interests were elicited and leveraged during firsthand and secondhand data activities, the secondhand data activities took this one step further by offering meaning and purpose for the NGSS HS-PS1-5 sensemaking.

**Highlighting relevance and purpose**

The NOAA and EPA databases enabled students to investigate places associated with their own communities—places they, or their family members, have lived or visited. Research and experience suggest that students are more engaged when the study focus is of relevance and interest to students (Penuel et al. 2017). The exploration of issues that currently impact students’ communities—such as pressing and complex envi-

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**FIGURE 9**

Sample student graphs representing relationship between air temperature and ozone concentration in Danbury, Connecticut, during April, June, and August 2017.

Calculation of correlation coefficient, coefficient of determination, and slope facilitated arguments and explanations about what may account for variation.
ronmental problems—provides opportunities for students to meaningfully and creatively apply and expand knowledge.

Thanks to the public availability of geoscience databases, all residents can actively engage in surfacing, exploring, and resolving community environmental issues. Having one of the state’s 11 air quality stations located within the community—a former industrial city with a population of nearly 85,000 residents—helped make the feasibility of monitoring and comparing air quality conditions more visible to students. The secondhand activities have a purpose beyond an opportunity to demonstrate state science expectations; they offer motivation for learning because of their connection to the community (Yeager and Bundick 2009), and can foster the development of skills and resource awareness that support grassroots environmental justice activities.

Community representation in the databases was not the only factor that supported relevance in the secondhand data activities. The two geoscience data sets also created a connection to students’ emerging career identities and knowledge. The state is reported to have relatively poor air quality (Shay 2019; American Lung Association 2020) and all the students are enrolled in state-funded career preparation programs designed to advance green building and technology. Since workforce training in careers such as heating, ventilation, and air conditioning (HVAC); automotive; and carpentry includes efforts to reduce the emission of ground-level ozone precursors, I anticipated that students would share their emerging career knowledge as the secondhand-data activities unfolded. In this way students’ career identities and the school’s mission intersected with the focus of study.

Making STEM career pathways more visible
As an added plus, each geoscience database has at least one point of contact to whom students and teachers can direct questions. As part of agency funding expectations, many university geoscientists engage in public outreach (National Alliance for Broader Impacts 2016). The products of these efforts may be found in well-organized, informative websites, as well as professional learning workshops (Table 2; see Online Connections). These resources, which sometimes include step-by-step online tutori-
als and participant stipends, can jumpstart the establishment of a broader community of practice. As related to my highlighted efforts to design NGSS HS-PS1-5 activities, several of these workshops informed and/or inspired the design of activities that extended beyond the school community.

Students remotely investigated historic challenges of global air pollution with Chinese high school students (Kelly 2019b) and explored mitigation strategies with the support of mentor scientists (Kelly 2019b; Rodriguez and Walsh 2018). This fostered development of a community of practice both within and beyond school boundaries (Basu et al. 2009; Kelly and Vincent 2018) which enhanced students’ existing and emerging identities as the secondhand geoscience data activities unfolded. Through participation in a science community, students were positioned to see themselves—and to be seen—as contributors to the development and sharing of new knowledge.

ONLINE CONNECTIONS

Table 1—Connecting to the Next Generation Science Standards: https://bit.ly/39h5jWp

Table 2—Databases: https://bit.ly/3msGDV

Table 3—Learning Progressions: https://bit.ly/3d7pYNv

Table 4—Science and Engineering Practices: https://bit.ly/31hChRZ

REFERENCES


