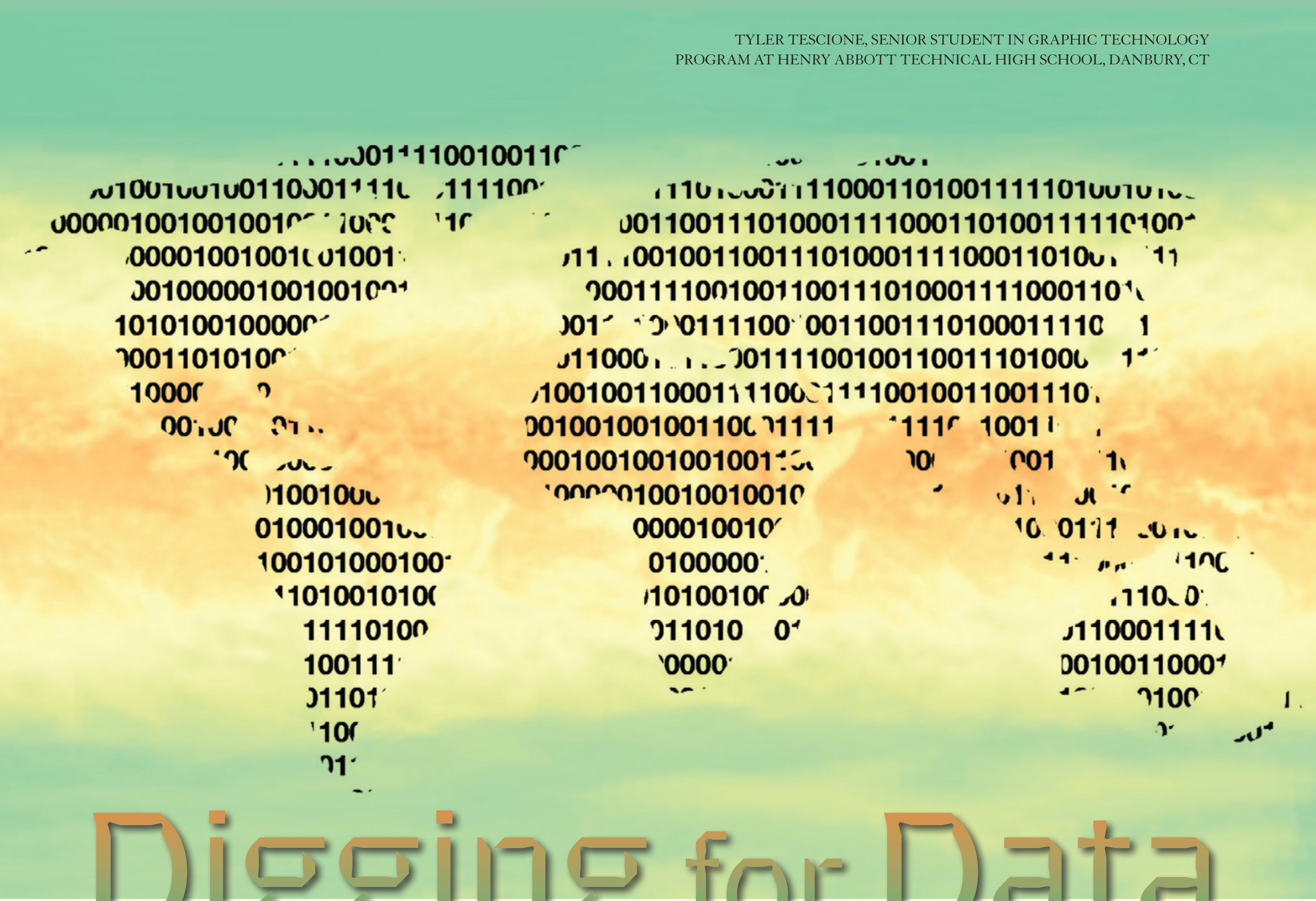


TYLER TESCIONE, SENIOR STUDENT IN GRAPHIC TECHNOLOGY
PROGRAM AT HENRY ABBOTT TECHNICAL HIGH SCHOOL, DANBURY, CT

Digging for Data

Mining geoscience databases to deepen and expand STEM learning opportunities

SUSAN MEABH KELLY

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) (NextGenScience 2020), prioritizing products of science education organizations and agency-funded studies.

Implementing new high school science expectations

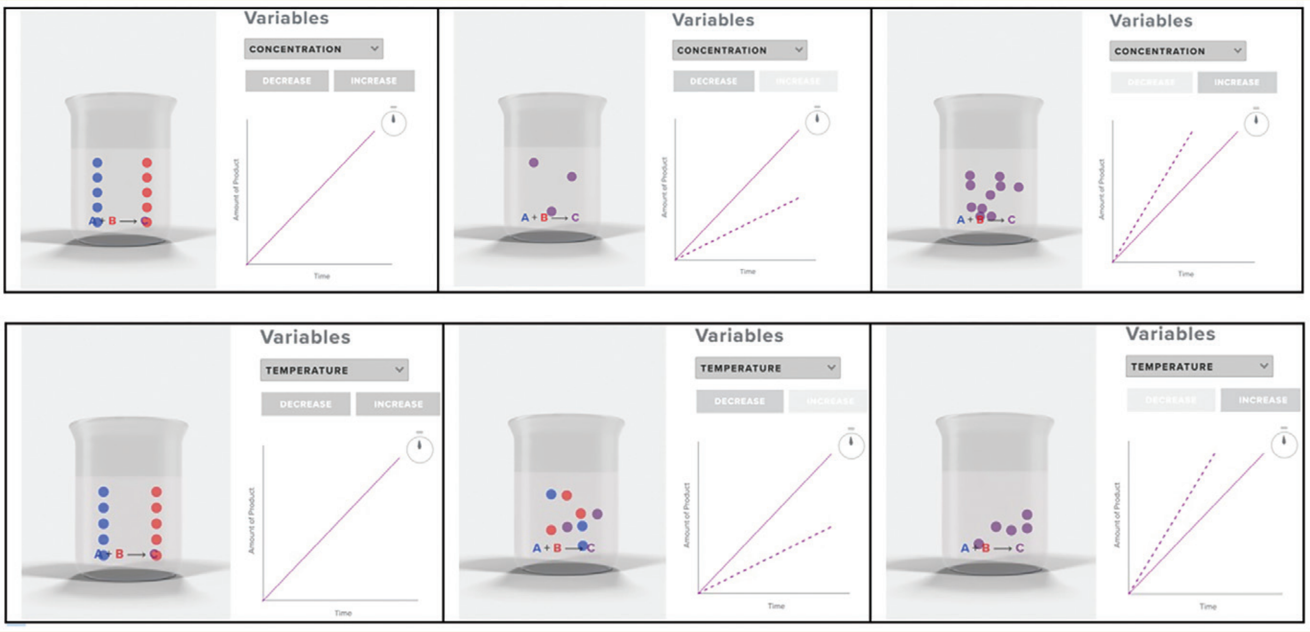
Building on students' prior exploration of NGSS MS-PS1-4 and associated atomic-molecular theory activities (Michaels, Shouse, and Schweingruber 2008), I kicked off a sequence of firsthand data activities by prompting students to record and make sense of their observations of a popular chemistry demonstration—the 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 × 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

FIGURE 1

Interactive reaction rate simulation: Effect of concentration (ACS 2020).



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

FIGURE 2

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

Science SCASS (2018) and Penuel and Van Horne (2016) offer guidance and ideas for crosscutting concepts prompts.

- 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?

TABLE 2

Sample secondhand data resources: Geoscience databases.

NGSS HS Performance Expectation	Geoscience Database	Relevant Education Resources
HS-ESS3-4 Earth and Human Activity	Clean Air Status and Trends Network (CASTNET) (EPA 2020d) AURA (NASA 2020d)	Air quality-climate-vegetation interactions (Fiore and Clifton 2016) Global challenge, global collaboration (Kelly 2019b)
HS-ESS3-5 Earth and Human Activity	Sea level change (USGS 2020e) Sea level trends (NOAA 2020f)	USGS: Sea level and climate (USGS 2020f) Data in the classroom: Investigating sea level (NOAA 2020g)
HS-ESS3-6 Earth and Human Activity	Ocean carbon and acidification data portal (NOAA 2020b) Ocean acidification observations and data (NOAA 2020c).	Ocean acidification (NOAA 2020d) Data in the classroom: Ocean acidification (NOAA 2020e)
HS-ESS1-3 Earth's Place in the Universe	Data access for SDSS D12 overview (SDSS 2020a) Spectroscopy lab (USGS 2020d)	Education and public outreach (SDSS 2020b) Stellar spectroscopy (NOAO 2008)
HS-ESS1-5 Earth's Place in the Universe	Data at IRIS (IRIS 2020a) Data (UNAVCO 2020a)	Education and public outreach (IRIS 2020b) Data for educators (UNAVCO 2020b)
HS-ESS2-2 Earth's Systems	Available groundwater recharge data (USGS 2020a) Data and tools (USGS 2020b)	Groundwater storage and the water cycle (USGS 2020c) Model my watershed (Stroud Water Research Center 2020)
HS-ESS2-5 Earth Systems	Sea surface temperature (NASA 2020a) Earth data (NASA 2020b)	Daily Sea Surface Temperatures (NASA 2020e) The water cycle: Heating the ocean (NASA 2020c)

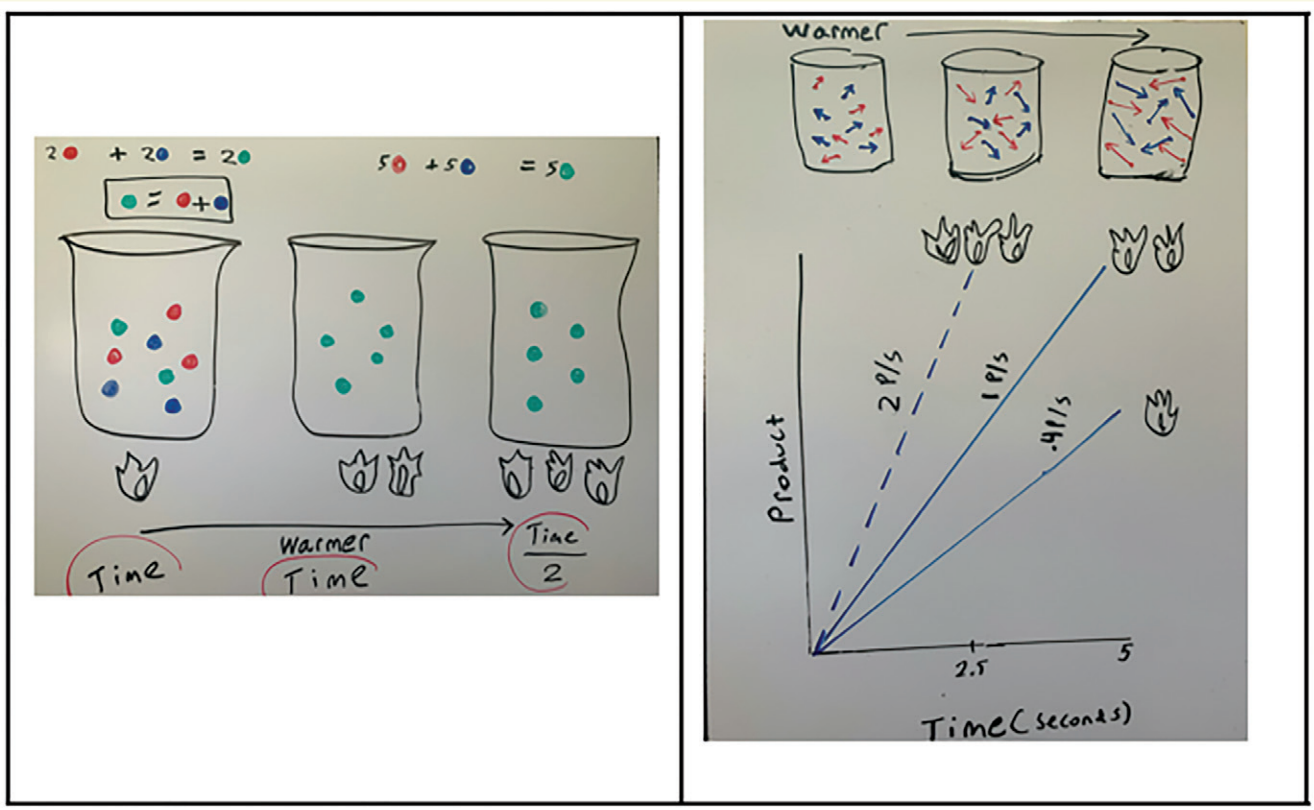
period of time. As before, I shifted from team to team to listen, observe, and prompt students' thinking, using HS-PS1-5's crosscutting concept of patterns as a lever (Figure 2), students collaboratively constructed understanding towards the targeted disciplinary core idea. Applying professional learning 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).

FIGURE 4

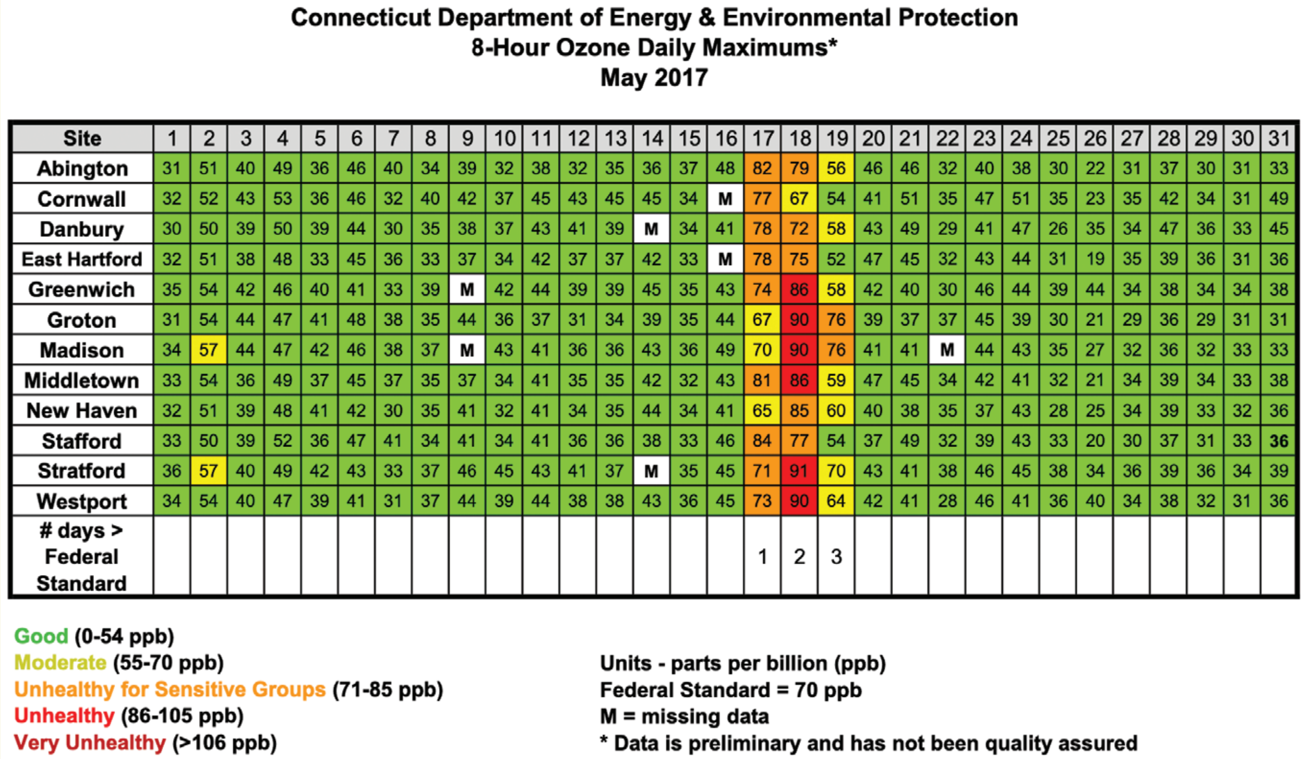
Current locations of Connecticut EPA ozone stations (EPA 2020).

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 teams' 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

FIGURE 5

May 2017 8-Hour ozone daily maximum at Connecticut ozone stations (CT-DEEP 2020).



Connecticut Department of Energy & Environmental Protection
8-Hour Ozone Daily Maximums*
May 2017

Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Abington	31	51	40	49	36	46	40	34	39	32	38	32	35	36	37	48	82	79	56	46	46	32	40	38	30	22	31	37	30	31	33
Cornwall	32	52	43	53	36	46	32	40	42	37	45	43	45	45	34	M	77	67	54	41	51	35	47	51	35	23	35	42	34	31	49
Danbury	30	50	39	50	39	44	30	35	38	37	43	41	39	M	34	41	78	72	58	43	49	29	41	47	26	35	34	47	36	33	45
East Hartford	32	51	38	48	33	45	36	33	37	34	42	37	37	42	33	M	78	75	52	47	45	32	43	44	31	19	35	39	36	31	36
Greenwich	35	54	42	46	40	41	33	39	M	42	44	39	39	45	35	43	74	86	58	42	40	30	46	44	39	44	34	38	34	34	38
Groton	31	54	44	47	41	48	38	35	44	36	37	31	34	39	35	44	67	90	76	39	37	37	45	39	30	21	29	36	29	31	31
Madison	34	57	44	47	42	46	38	37	M	43	41	36	36	43	36	49	70	90	76	41	41	M	44	43	35	27	32	36	32	33	33
Middletown	33	54	36	49	37	45	37	35	37	34	41	35	35	42	32	43	81	86	59	47	45	34	42	41	32	21	34	39	34	33	38
New Haven	32	51	39	48	41	42	30	35	41	32	41	34	35	44	34	41	65	85	60	40	38	35	37	43	28	25	34	39	33	32	36
Stafford	33	50	39	52	36	47	41	34	41	34	41	36	36	38	33	46	84	77	54	37	49	32	39	43	33	20	30	37	31	33	**36**
Stratford	36	57	40	49	42	43	33	37	46	45	43	41	37	M	35	45	71	91	70	43	41	38	46	45	38	34	36	39	36	34	39
Westport	34	54	40	47	39	41	31	37	44	39	44	38	38	43	36	45	73	90	64	42	41	28	46	41	36	40	34	38	32	31	36
# days > Federal Standard																	1	2	3												

Good (0-54 ppb)
Moderate (55-70 ppb)
Unhealthy for Sensitive Groups (71-85 ppb)
Unhealthy (86-105 ppb)
Very Unhealthy (>106 ppb)

Units - parts per billion (ppb)
Federal Standard = 70 ppb
M = missing data
*** Data is preliminary and has not been quality assured**

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

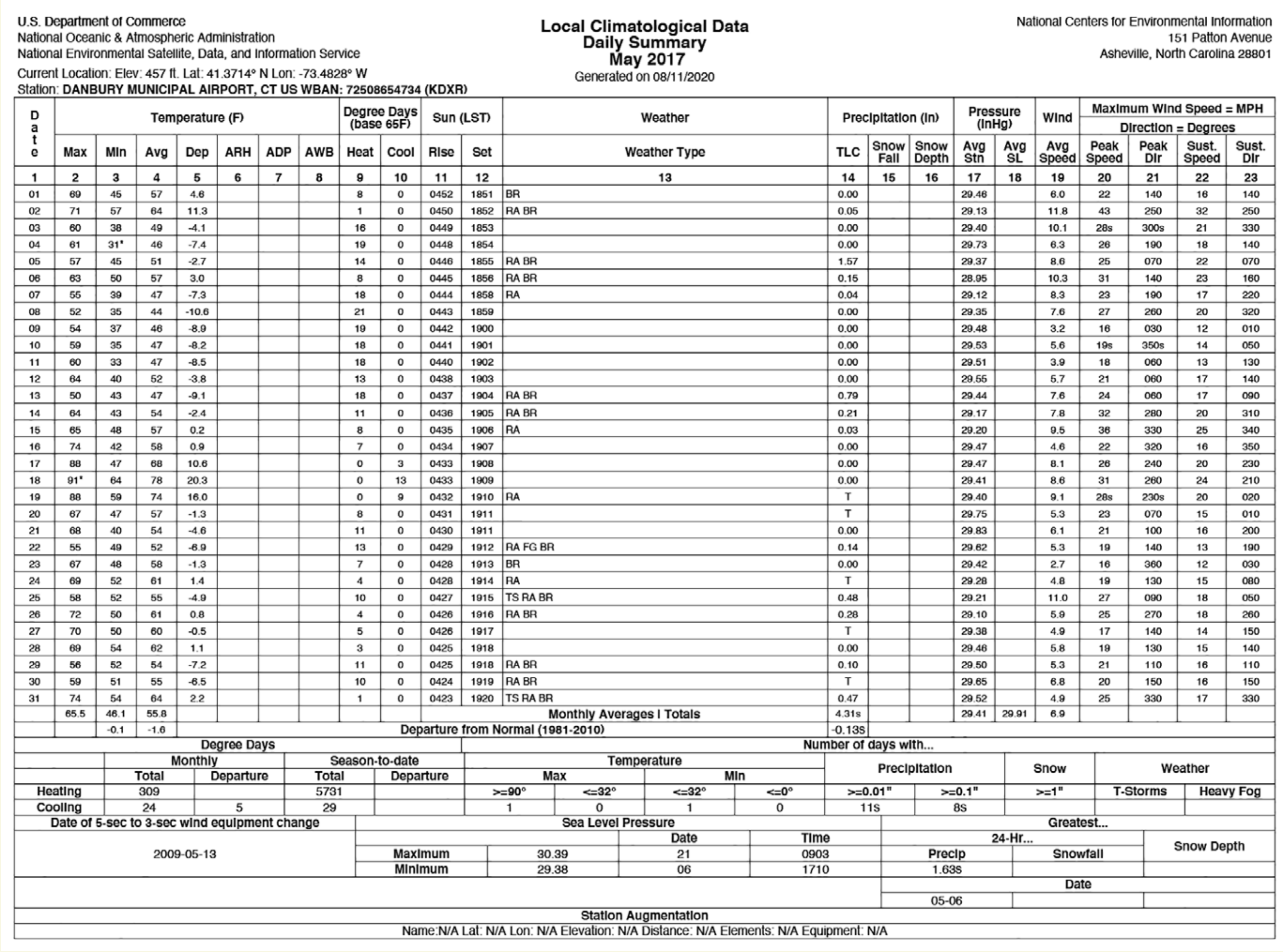
While firsthand data activities are valuable, classroom experience and research suggest that access to a range of data types gives students opportunities to apply a greater number of scientific practices (Hug and McNeill 2008) and facilitates the development of a deeper understanding of the investigated 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 (Magnusson 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

FIGURE 6

May 2017 Daily weather data for Danbury Municipal Airport.



U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service
Current Location: Elev: 457 ft. Lat: 41.3714° N Lon: -73.4828° W
Station: **DANBURY MUNICIPAL AIRPORT, CT US WBAN: 72508654734 (KDXR)**

Local Climatological Data
Daily Summary
May 2017
Generated on 08/11/2020

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Date	Temperature (F)							Degree Days (base 65F)		Sun (LST)		Weather	Precipitation (In)			Pressure (InHg)		Wind	Maximum Wind Speed = MPH Direction = Degrees			
	Max	Min	Avg	Dep	ARH	ADP	AWB	Heat	Cool	Rise	Set	Weather Type	TLC	Snow Fall	Snow Depth	Avg Stn	Avg SL	Avg Speed	Peak Speed	Peak Dir	Sust. Speed	Sust. Dir
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
01	69	45	57	4.6				8	0	0452	1851	BR	0.00			29.46		6.0	22	140	16	140
02	71	57	64	11.3				1	0	0450	1852	RA BR	0.05			29.13		11.8	43	250	32	250
03	60	38	49	-4.1				16	0	0449	1853		0.00			29.40		10.1	28s	300s	21	330
04	61	31*	46	-7.4				19	0	0448	1854		0.00			29.73		6.3	26	190	18	140
05	57	45	51	-2.7				14	0	0446	1855	RA BR	1.57			29.37		8.6	25	070	22	070
06	63	50	57	3.0				8	0	0445	1856	RA BR	0.15			28.95		10.3	31	140	23	160
07	55	39	47	-7.3				18	0	0444	1858	RA	0.04			29.12		8.3	23	190	17	220
08	52	35	44	-10.6				21	0	0443	1859		0.00			29.35		7.6	27	260	20	320
09	54	37	46	-8.9				19	0	0442	1900		0.00			29.48		3.2	16	030	12	010
10	59	35	47	-8.2				18	0	0441	1901		0.00			29.53		5.6	19s	350s	14	050
11	60	33	47	-8.5				18	0	0440	1902		0.00			29.51		3.9	18	060	13	130
12	64	40	52	-3.8				13	0	0438	1903		0.00			29.55		5.7	21	060	17	140
13	50	43	47	-9.1				18	0	0437	1904	RA BR	0.79			29.44		7.6	24	060	17	090
14	64	43	54	-2.4				11	0	0436	1905	RA BR	0.21			29.17		7.8	32	280	20	310
15	65	48	57	0.2				8	0	0435	1906	RA	0.03			29.20		9.5	36	330	25	340
16	74	42	58	0.9				7	0	0434	1907		0.00			29.47		4.6	22	320	16	350
17	88	47	68	10.6				0	3	0433	1908		0.00			29.47		8.1	26	240	20	230
18	91*	64	78	20.3				0	13	0433	1909		0.00			29.41		8.6	31	260	24	210
19	88	59	74	16.0				0	9	0432	1910	RA	T			29.40		9.1	28s	230s	20	020
20	67	47	57	-1.3				8	0	0431	1911		T			29.75		5.3	23	070	15	010
21	68	40	54	-4.6				11	0	0430	1911		0.00			29.83		6.1	21	100	16	200
22	55	49	52	-6.9				13	0	0429	1912	RA FG BR	0.14			29.62		5.3	19	140	13	190
23	67	48	58	-1.3				7	0	0428	1913	BR	0.00			29.42		2.7	16	360	12	030
24	69	52	61	1.4				4	0	0428	1914	RA	T			29.28		4.8	19	130	15	080
25	58	52	55	-4.9				10	0	0427	1915	TS RA BR	0.48			29.21		11.0	27	090	18	050
26	72	50	61	0.8				4	0	0426	1916	RA BR	0.28			29.10		5.9	25	270	18	260
27	70	50	60	-0.5				5	0	0426	1917		T			29.38		4.9	17	140	14	150
28	69	54	62	1.1				3	0	0425	1918		0.00			29.46		5.8	19	130	15	140
29	56	52	54	-7.2				11	0	0425	1918	RA BR	0.10			29.50		5.3	21	110	16	110
30	59	51	55	-6.5				10	0	0424	1919	RA BR	T			29.65		6.8	20	150	16	150
31	74	54	64	2.2				1	0	0423	1920	TS RA BR	0.47			29.52		4.9	25	330	17	330
	65.5	46.1	55.8							Monthly Averages I Totals			4.31s			29.41	29.91	6.9				
		-0.1	-1.6	Departure from Normal (1981-2010)									-0.13S									

Degree Days					Number of days with...								
	Monthly		Season-to-date		Temperature				Precipitation		Snow	Weather	
	Total	Departure	Total	Departure	Max		Min						
Heating	309		5731		>=90°	<=32°	<=32°	<=0°	>=0.01"	>=0.1"	>=1"	T-Storms	Heavy Fog
Cooling	24	5	29		1	0	1	0	11S	8S			

Date of 5-sec to 3-sec wind equipment change	Sea Level Pressure				Greatest...		
			Date	Time	24-Hr...		Snow Depth
2009-05-13	Maximum	30.39	21	0903	Precip	Snowfall	
	Minimum	29.38	06	1710	1.63S		
					Date		
					05-06		

Station Augmentation
Name:N/A Lat: N/A Lon: N/A Elevation: N/A Distance: N/A Elements: N/A Equipment: N/A

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 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

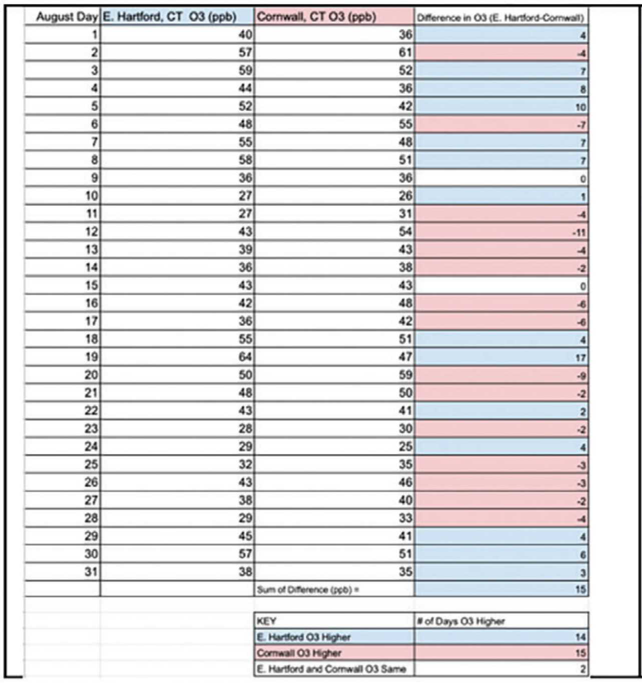
Sample secondhand data prompts, leveraging the crosscutting concept of patterns.

- 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**?

FIGURE 8

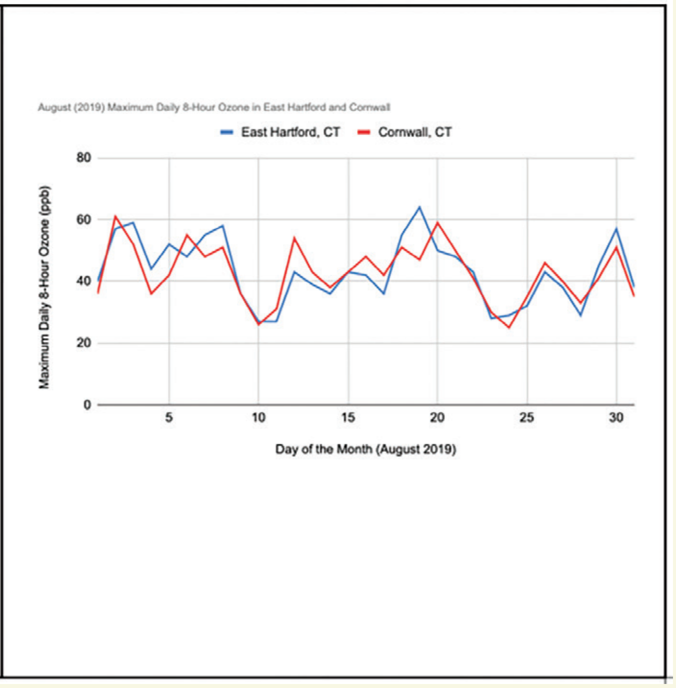
Sample student data table comparing rural (Cornwall) and urban (East Hartford) ozone concentrations at similar latitude in Connecticut during August 2019.

There are no air temperature stations at these locations, so a creative and arguable solution to compare two neighboring inland stations at similar latitude was prompted.



August Day	E. Hartford, CT O3 (ppb)	Cornwall, CT O3 (ppb)	Difference in O3 (E. Hartford-Cornwall)
1	40	36	4
2	57	61	-4
3	59	52	7
4	44	36	8
5	52	42	10
6	48	55	-7
7	55	48	7
8	58	51	7
9	36	36	0
10	27	26	1
11	27	31	-4
12	43	54	-11
13	39	43	-4
14	36	38	-2
15	43	43	0
16	42	48	-6
17	36	42	-6
18	55	51	4
19	64	47	17
20	50	59	-9
21	48	50	-2
22	43	41	2
23	28	30	-2
24	29	25	4
25	32	35	-3
26	43	46	-3
27	38	40	-2
28	29	33	-4
29	45	41	4
30	57	51	6
31	38	35	3
		Sum of Difference (ppb) =	15

KEY	# of Days O3 Higher
E. Hartford O3 Higher	14
Cornwall O3 Higher	15
E. Hartford and Cornwall O3 Same	2



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 secondhand 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 first- 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.

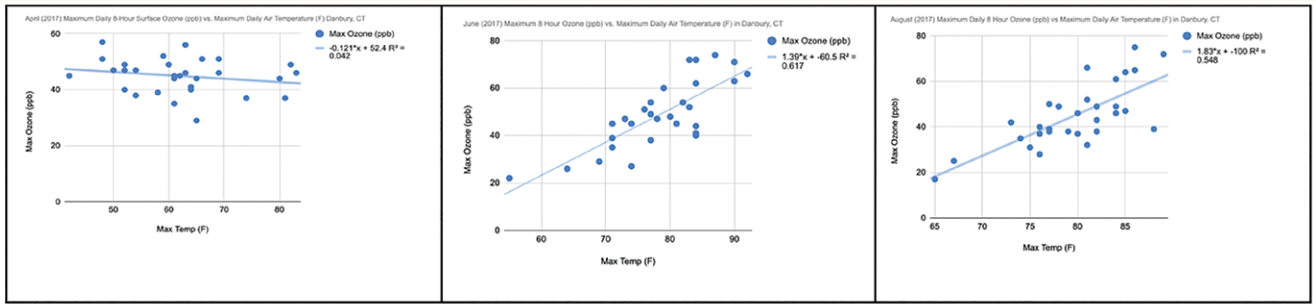
Highlighting relevance and purpose

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-

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.

Community representation in the databases was not the only factor that supported relevance in the secondhand data activities. The two geoscience datasets also created a connection to students' emerging career identities and knowledge.

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 tutorials 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/3rnsGDV*

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

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

REFERENCES

Achieve. 2013a. *Appendix D –"All standards, all students": Making the next generation science standards accessible for all students*. https://www.nextgenscience.org/sites/default/files/Appendix%20D%20Diversity%20and%20Equity%206-14-13.pdf

Achieve. 2013b. *Appendix F – Science and engineering practices in the NGSS*. https://www.nextgenscience.org/sites/default/files/resource/files/Appendix%20F%20%20Science%20and%20Engineering%20Practices%20in%20the%20NGSS%20-%20FINAL%20060513.pdf

Achieve. 2015. *Evidence statement: HS-PS1-5*. https://www.nextgenscience.org/sites/default/files/evidence_statement/black_white/HS-PS1-5%20Evidence%20Statements%20June%202015%20asterisks.pdf

AirNow. 2020. Air quality flag program. https://www.airnow.gov/air-quality-flag-program/

American Chemical Society (ACS). 2020. Classroom Resources: Reactions & Stoichiometry. https://teachchemistry.org/classroom-resources/reaction-rates-simulation

American Lung Association. 2020. State of the air report: Connecticut (ozone). http://www.stateoftheair.org/city-rankings/states/connecticut/

Basu, S., A. Barton, N. Clairmont, and D. Locke. 2009. Developing a framework for critical agency through case study in a conceptual physics context. *Cultural Studies in Science Education* 4 (2): 345–371 .

Connecticut Department of Energy and Environmental Protection (CT-DEEP). 2020. *Annual Summary Information for Ozone*. https://portal.ct.gov/DEEP/Air/Monitoring/Annual-Summary-Information-for-Ozone

Connecticut State Department of Education. 2019. Next Generation Science Standards (NGSS) cluster/item specifications: Specifications for high school. https://ct.portal.cambiumast.com/core/fileparse.php/51/urlt/High-School-Science-Specifications.pdf

Common Core State Standards Initiative. 2020a. *Mathematics standards.* http://www.corestandards.org/Math/

Common Core State Standards Initiative. 2020b. English language arts standards. http://www.corestandards.org/ELA-Literacy/

Science SCASS. 2018. Using crosscutting concepts to prompt student responses. https://files.eric.ed.gov/fulltext/ED586953.pdf

Darling-Hammond, L. 2000. New standards and old inequalities: School reform and the education of African-American students. *The Journal of Negro Education* 69 (4): 263–287.

Department of Geosciences, SUNY/Stony Brook. 2009. Ground level ozone workshop [Professional Development Workshop]. https://www.geo.sunysb.edu/bad-ozone/Workshops.html

Duschl, R. 1990. *Restructuring science education. The importance of theories and their development*. New York: Teachers College Press.

Duschl, R. 2012. The second dimension—crosscutting concepts: Understanding *A Framework for K–12 Science Education*. *The Science Teacher* 79 (2).

Environmental Protection Agency. 2016. *Atmospheric concentrations of greenhouse gases*. https://www.epa.gov/sites/production/files/2016-08/documents/print_ghg-concentrations-2016.pdf

Environmental Protection Agency. 2020a. *Ozone Monitors in New England*. https://www3.epa.gov/region1/airquality/omssites.html

Environmental Protection Agency. 2020b. *Ground level ozone basics*. https://www.epa.gov/ground-level-ozone-pollution/ground-level-ozone-basics

Environmental Protection Agency. 2020c. V*olatile organic compounds' impact on indoor air quality*. https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality

Environmental Protection Agency. 2020d. Clean Air Status and Trends Network (CASTNET). https://www.epa.gov/castnet

Environmental Protection Agency. 2020e. Trends in ozone adjusted for weather conditions. https://www.epa.gov/air-trends/trends-ozone-adjusted-weather-conditions

Fiore, A., and O. Clifton. 2016. *Air quality-climate-vegetation interactions* [Workshop Presentation]. Earth2Class, Lamont Doherty Earth Observatory of Columbia University, Palisades, NY. https://earth2class.org/site/?p=9804

Fischetti, M. 2014. The paradox of pollution-producing trees: Why some greenery can make smog worse. *Scientific American*, 310 (6). https://www.scientificamerican.com/article/the-paradox-of-pollution-producing-trees/

Hug, B., and K. McNeill. 2008. Use of first-hand and second-hand data in science: Does data type influence classroom conversations? *International Journal of Science Education* 30 (13): 1725–1751.

Incorporated Research Institutions for Seismology (IRIS). 2020a. Data at IRIS. http://www.iris.washington.edu/ds/nodes/dmc/data/

IRIS. 2020b. Education and public outreach. https://www.iris.edu/hq/programs/epo

Jackson, J., L. Dukerich, and D. Hestenes. 2008. Modeling Instruction: An effective model for science education. *Science Educator* 17 (1): 10–17. http://modeling.asu.edu/modeling/ModInstrArticle_NSELAspr08.pdf

Jenkins, J., and E. Howard. 2019. Implementation of Modeling Instruction in a high school chemistry unit on energy and states of matter. *Science Education International* 30 (2): 97–104. https://eric.ed.gov/?id=EJ1218432

Kanari, Z., and R. Millar. 2004. Reasoning from data: How students collect and interpret data in science investigations. *Journal of Research in Science Teaching* 41 (7): 448–769.

Kelly, S., and S. Vincent. 2018. *Navigating systems to expand possibilities* [Conference poster]. American Geophysical Union meeting. Washington, D.C. https://agu.confex.com/agu/fm18/meetingapp.cgi/Paper/458525

Kelly, S. 2019a. *Assessment Development Guidelines*. https://www.ngssassessmenttools.com/portfolio .

Kelly, S. 2019b. *Global challenge, global collaboration: International secondary students collaboratively explore air quality issues in historical context* [Conference presentation]. NASA Health and Air Quality Applied Sciences

Team Meeting, Pasadena, CA, United States. https://haqast.org/wp-content/uploads/sites/91/2019/08/HAQAST6_Poster_Kelly.pdf

Kessler, J. 2013. *NSTA web seminars: Chemical change*. [Powerpoint Slides]. National Science Teaching Association: https://learningcenter.nsta.org/products/symposia_seminars/ACS/files/ChemicalChange–IntroducingaFreeOnlineResourceforMiddleSchoolChemistry.pdf

MacIsaac, D. 2002. Whiteboarding in the classroom. http://physicsed.buffalostate.edu/AZTEC/BP_WB/index.html

Magnusson, S., A. Palincsar, S. Hapgood, and A. Lomangino. 2004. How should learning be structured in inquiry-based science instruction?: Investigating the interplay of 1st- and 2nd- hand investigations. In *Proceedings of the Sixth International Conference of the Learning Sciences,* eds. Y. Kafai, W. Sandoval, N. Enyedy, A. Nixon, & F. Herrera, pp. 310–317. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Michaels, S., A. Shouse, and H. Schweingruber. 2008. *Ready, set, science! Putting research to work in K–8 science classrooms*. Washington, DC: National Academies Press.

National Aeronautics and Space Administration (NASA). 2003. *Chemistry in the sunlight*. https://earthobservatory.nasa.gov/features/ChemistrySunlight/chemistry_sunlight3.php

NASA/IPAC Teacher Archive Research Program. 2020. How it works. https://nitarp.ipac.caltech.edu

NASA. 2020a. Sea surface temperature. https://neo.sci.gsfc.nasa.gov/view.php?datasetId=MYD28M&year=2018

NASA. 2020b. Earth data. https://earthdata.nasa.gov

NASA. 2020c. The water cycle: Heating the ocean. https://gpm.nasa.gov/education/videos/water-cycle-heating-ocean

NASA. 2020d. Aura. https://eospso.nasa.gov/missions/aura

National Alliance for Broader Impacts. 2016. *Guiding principles*. https://www.researchinsociety.org/guiding-principles

National Center for Education Statistics. 2018. *Table 702.2: Percentage of children ages 3 to 18 who use the internet, among those who use the internet, percent using it in various locations by selected child and family characteristics, 2011 and 2017*. https://nces.ed.gov/programs/digest/d18/tables/dt18_702.20.asp?current=yes

National Centers for Environmental Information. 2020. *Data tools: Local climatological data*. https://www.ncdc.noaa.gov/cdo-web/datatools/lcd

National Oceanic and Atmospheric Administration (NOAA). 2020a. Ocean carbon and acidification data portal. https://www.ncei.noaa.gov/access/oads/

NOAA. 2020b. Ocean acidification observations and data. https://www.pmel.noaa.gov/co2/story/OA+Observations+and+Data

NOAA. 2020c. Ocean acidification. https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification

NOAA. 2020d. Data in the classroom: Ocean acidification. https://dataintheclassroom.noaa.gov/content/ocean-acidification

NOAA. 2020e. Sea level trends. https://tidesandcurrents.noaa.gov/sltrends/

NOAA. 2020f. Data in the classroom: Investigating sea level. https://dataintheclassroom.noaa.gov/content/sea-level

National Optical Astronomy Observatory (NOAO). 2008. Stellar spectroscopy. http://rbseu.uaa.alaska.edu/projects/spectroscopy/Stellar%20Spectroscopy.pdf

National Research Council (NRC). 1999. *Testing, Teaching, and Learning: A Guide for States and School Districts.* Board on Testing and Assessment, Commission on Behavioral and Social Sciences and Education. Washington, DC: National Academies Press. https://www.nap.edu/read/9609/chapter/9

National Science Teaching Association. 2013. Matrix of crosscutting concepts in NGSS. https://static.nsta.org/ngss/MatrixOfCrosscuttingConcepts.pdf

NextGenScience. 2020. HS-PS1-5 Matter and its interactions. https://www.nextgenscience.org/pe/hs-ps1-5-matter-and-its-interactions

Noschese, F. 2010. The $2 interactive whiteboard. https://fnoschese.wordpress.com/2010/08/06/the-2-interactive-whiteboard/

Osborne, J., S. Collins, M. Ratcliffe, R. Millar, and R. Duschl. 2003. What "ideas-about-science" should be taught in school science? A Delphi study of an expert community. *Journal of Research in Science Teaching* 40 (7): 692–720.

Pearson, A., J. Schuldt, R. Romero-Canyas, M. Ballew, and D. Larson-Konar. 2018. Diverse segments of the US public underestimate the environmental concerns of minority and low-income Americans. *Proceedings of the National Academy of Sciences* 115 (49): 12429–12434. https://www.pnas.org/content/115/49/12429

Penuel, W., K. Van Horne, J. Jacobs, T. Sumner, D. Watkins, and D. Quigley. 2017. *Developing NGSS-aligned curriculum that connects to students' interests and experiences: Lessons learned from a co-design partnership* [Conference Paper]. NARST.

Penuel, W., and K. Van Horne. 2016. STEM Teaching Tool practice brief 41: Prompts for integrating crosscutting concepts into assessment and instruction. http://stemteachingtools.org/assets/landscapes/STEM-Teaching-Tool-41-Cross-Cutting-Concepts-Prompts.pdf

Rodriguez, J., and H. Walsh. 2018. *Comparison of impact of ground level ozone pollution on ozone-sensitive and ozone-tolerant snap beans* [Conference Presentation]. American Geophysical Union, Washington, D.C. https://agu.confex.com/agu/fm18/meetingapp.cgi/Session/43555

Shay, J. 2019. Connecticut ozone pollution among worst in U.S. *Connecticut Post*. https://www.ctpost.com/local/article/Connecticut-still-among-worst-in-U-S-with-ozone-13791081.php

Sloan Digital Sky Survey (SDSS). 2020a Data access for SDSS D12 overview. https://www.sdss.org/dr12/data_access/

SDSS. 2020b. Education and public engagement. https://www.sdss.org/education/

Stroud Water Research Center. 2020. Model my watershed. https://stroudcenter.org/virtual-learning-resource/model-my-watershed/

TheAzmanam. 2016. Iodine clock reaction timed to Tchaikovsky's *Russian Dance* from *The Nutcracker* [Video]. https://www.youtube.com/watch?v=Y5EQTkwMByg

University NAVSTAR Consortium (UNAVCO). 2020a. Data. https://www.unavco.org/data/data.html

UNAVCO. 2020b. Data for educators. https://www.unavco.org/education/resources/data-for-educators/data-for-educators.html

United States Geological Survey (USGS). 2020a. Available groundwater recharge data. https://water.usgs.gov/ogw/gwrp/activities/HydCompData.html

USGS. 2020b. Data and tools. https://www.usgs.gov/products/data-and-tools/real-time-data/water

USGS. 2020c. Groundwater storage and the water cycle. https://www.usgs.gov/special-topic/water-science-school/science/groundwater-storage-and-water-cycle?qt-science_center_objects=0#qt-science_center_objects

USGS. 2020d. Spectroscopy lab. https://www.usgs.gov/labs/spec-lab

USGS. 2020e. Sea level change. https://www.usgs.gov/centers/whcmsc/science/sea-level-change?qt-science_center_objects=0#qt-science_center_objects

USGS. 2020f. Sea level and climate. https://www.usgs.gov/special-topic/water-science-school/science/sea-level-and-climate?qt-science_center_objects=0#qt-science_center_objects

Yeager, D., and M. Bundick. 2009. The role of purposeful work goals in promoting meaning in life and in schoolwork during adolescence. *Journal of Adolescent Research* 24: 423–452

Susan Meabh Kelly (*meabhkelly@protonmail.com*) is a PhD candidate and high school teacher in Danbury, CT.