Teaching Air Quality and Data Visualization Using Tangible Models for Middle Schoolers

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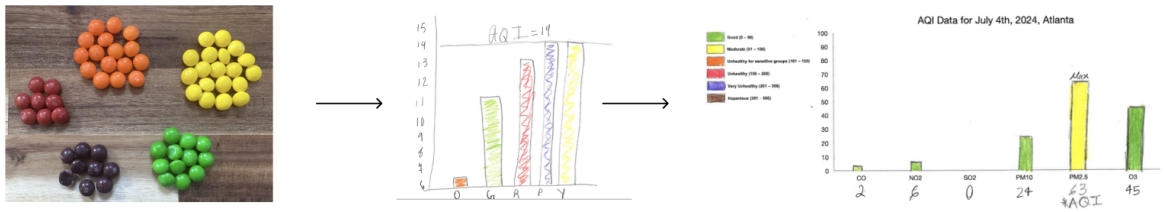

Part 1: Identifying the Driver Skittle and SCI

Part 2: Creating a chart for Skittles data

Part 3: Bridging SCI to AQI

Figure 1: A demonstration of the three-step activity. In this activity, students first sorted tangible candy pieces (left) to determine the count of each color, then represented this data using preliminary graphs in different chart types (center). The candy served as a physical model to represent air pollutants, scaffolding students toward creating graphs of real-world pollution data (right).

Abstract

In this paper, we introduce a tangible interaction activity we created using colored candies as a model to explain both the Air Quality Index (AQI) and foundational data visualization design concepts. This activity is a part of a two-week Data Visualization and the Environment (DVE) summer camp for middle school students. DVE students spend one week learning the basics of air quality, environmental data, and fundamentals of data visualization principles and software (e.g., spreadsheets, Tableau), and during the second week, students conduct a data investigation on a topic of their own interest. This paper outlines the activity's design, including its steps, materials, and learning objectives. Through data analysis on students' worksheets and in-activity observation, we provide reflections on students' experiences, along with challenges encountered and future opportunities for similar educational activities.

Index Terms: Data Visualization Education, Constructive Visualization, Tangible Interaction.

1 Introduction

The World Health Organization has listed air pollution as the single largest environmental health risk [15]. In the US, most public interaction with air quality data comes through the U.S. Air Quality Index (AQI), which is maintained by the U.S. Environmental Protection Agency (EPA). It is calculated by computing a normalized value for five major pollutants regulated under the 1975 Clean Air Act: ground-level ozone, particulate matter (at both 2.5 micron and 10 micron sizes), carbon monoxide, sulfur dioxide, and nitrogen dioxide. These normalized values are presented on a 0-500 color-coded scale ranging from green ("Good") to maroon ("Hazardous"), based on the concentration levels at which each pollutant becomes increasingly dangerous to humans [16, 14]. The single pollutant with the highest normalized value in a 24-hour period is the driver pollutant, and that number alone is reported as the US AQI for that day [16]. Therefore, the AQI value by definition represents different pollutants on different days.

While many members of the public are familiar with the Air Quality Index (AQI) as a measure of the current air pollution levels in their local region, few people are able to explain what the AQI number means. The reported AQI is effective in communicating short-term health risks and supporting everyday decisions, but the simplified value obscures the underlying logic of its computation. The fact that different pollutants can "drive" the AQI on different days is often lost on the general public, leading to a fragmented understanding of what AQI really means and how data is used to measure it [3, 8]. The challenges of interpreting AQ data beyond the simplified AQI make it difficult for the public to engage in conversations about the causes, risks, and potential solutions to air pollution. Misconceptions, such as the assumption that the reported AQI represents a summation of multiple pollutant values rather than just the highest single value, lead to confusion and difficulty reasoning about long-term and systemic solutions and impacts of air pollution.

Prior work has demonstrated that data visualizations on air quality data can prompt users to speculate about sources of pollution, compare pollutant trends, and consider behavioral responses [3, 12], thus improving the public's understanding of the AQI concept. On the other hand, AQI data serves as an ideal topic to inspire public audiences' data reasoning. Understanding that the AQI represents the maximum value among six pollutants is not inherently intuitive. It requires a level of statistical literacy to grasp how this single value is derived from multiple dimensions of data. These complexities offer opportunities to foster data interpretation and trend analysis—key skills in both environmental science and data visualization education. Thus, we see value in both using AQI as a context to teach data visualization and using visualization to deepen understanding of AQI.

To address this goal, we ask the following question: How can we help K-12 students learn about both air quality and gain data visualization skills? Building on previous work in Constructive Visualization [7, 6], we developed a hands-on, candy-based classroom activity that helps students explore the structure of AQI while practicing data visualization skills. In this activity, we construct the metaphor of Skittles Color Index (SCI), mirroring how the AQI is calculated based on the driver pollutant. Students sort multi-colored Skittles® candies to construct multiple types of charts, helping them both vi-

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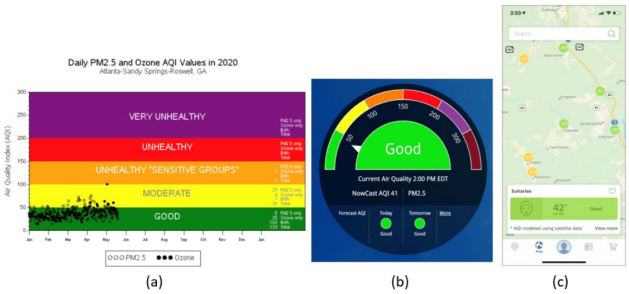

Figure 2: Existing AQI platform designs presented AQI data to the public: (a) Air Data - AQ Data Collected at Outdoor Monitors Across the US, www.epa.gov/outdoor-air-quality-data/air-data-aqi-plot; (b) AirNow Homepage, Reporting Area - Atlanta, GA https://www.airnow.gov; (c) Map Interface - screen taken from IQAir's AirVisual app. https://www.iqair.com/air-quality-app.

sualize and interpret air quality data through a physical and tangible process. This approach introduces students to the AQI concept and scaffolds their understanding of data encoding by making it visible, relatable, and accessible to K-12 students.

2 Why Skittles?

In recent years, the data visualization research community has explored a range of engaging approaches to support data visualization design pedagogy, particularly through creative and hands-on tools [1]. For example, VIZITCARDS [4] adopt the format of a board game, using a deck of structured prompts to guide students through the process of visualization design and promote collaborative thinking. The Comic Construction Kit [2] engages learners by having them construct explanatory data comics that illustrate different chart types and data stories. Tangible tokens, such as LEGO bricks, have also proven effective in engaging public audiences in creating data visualizations from raw data, as they promote a more active and intuitive understanding of data structures and patterns. Visualizations created with such tangible materials are known as constructive visualizations—they are naturally simple, dynamic, and expressive [7, 6]. This approach also aligns with the principles of Constructionism, which frames learning as a process of building knowledge through the creation of personally meaningful artifacts—what Papert called "objects to think with" [13]. Drawing on this idea, we selected Skittles®, a brand of fruit-flavored sugar candies, as the core material for our activity.

Playful materials have been shown to promote deeper cognitive processing, creativity, and engagement, especially when learning abstract or unfamiliar concepts [18]. The informal, familiar, and tangible nature of working with Skittles candies makes the activity inherently engaging for students, which also reduces the boredom around unfamiliar science and data topics. Each bag contains five distinct colors, which can be used to represent the five AQI pollutants, and the exact proportion of each color varies from bag to bag. Therefore, much as air quality has a different driver pollutant (the pollutant with the highest AQI value) on different days, students in this activity will have different "Driver Skittles," i.e., the color with the highest count. The logical mapping of color to flavor (e.g., lemon flavored Skittles are yellow) opens opportunities to talk about visualization conventions ("Why not use blue to represent lemon flavor?"), and slight variations, such as the occasional malformed or undersized candy piece, can spark a conversation about how to treat data anomalies. Additionally, Skittles are low-cost and widely available in grocery stores, making the activity more accessible for K-12 teachers to implement without requiring specialized

Skittles	Air Quality
• ***Driver Skittle Color*** — the color with the most pieces	• ***Driver Pollutant*** — the pollutant with the highest AQI value
• ***Skittle Color Index (SCI)*** — count of the Driver Skittle Color	• ***Air Quality Index (AQI)*** — AQI value of the Driver Pollutant

Figure 3: Mapping Skittle-based concepts to corresponding air quality concepts

equipment. Therefore, we adapted Skittles as the pedagogical tool for introducing AQI and data visualization.

3 Activity Design

The learning goal of this activity is for students to understand how AQI is constructed and be able to create a data visualization following the Domain-Purpose-Visual (DPV) framework [9] to explain this process. The DPV framework is a pedagogical tool designed to guide K-12 students through the data visualization design process in three stages: Domain (understanding the topic, audience, and context), Purpose (clarifying the goal of the visualization, e.g. "big ideas" of comparison, composition, relationship, and distribution), and Visual (selecting chart types and visual encodings). To be more specific, the learning objectives of this activity include:

- **LO1**: Define the Driver Pollutant as the pollutant that has the highest AQI value on a given day.
- **LO2**: Define the AQI of the day as the AQI value of the Driver Pollutant.
- **LO3**: Create multiple data visualizations highlighting different types of "big ideas."
- **LO4**: Create a data visualization on real-world AQI data following the DPV framework.

The research team collaborated with a middle school teacher recruited through Georgia Tech's GIFT (Georgia Intern-Fellowships for Teachers) program to design the activity. The design process focused on developing the overall structure of the activity with the teacher's curriculum and ensuring its appropriateness for middle school students. The resulting activity prototype was implemented with 24 students during the first year of our summer camp. Following this initial implementation, we engaged in two iterative refinement cycles. First, the research team conducted a workshop with 10 graduate students from the PI's research lab at Georgia Tech. In this session, we facilitated the full activity, followed by a group discussion to gather critical feedback on pacing, clarity, and opportunities for deeper learning engagement. Next, we conducted a professional development workshop with six K-12 teachers at the Georgia Science Teachers Association (GSTA) annual conference in early 2025. This session included an overview of the DPV framework [9], a demonstration of the Skittles activity, and a discussion in which teachers reflected on how they might adapt and implement the activity in their classrooms. Feedback from both sessions led to improvements in instructional scaffolding, vocabulary clarity, and the framing of conceptual transitions from Skittles to air quality data. These refinements informed the second-year implementation of the activity during the summer of 2025, with a new cohort of 18 middle school students from the Atlanta area and another middle school recruited through the GIFT program.

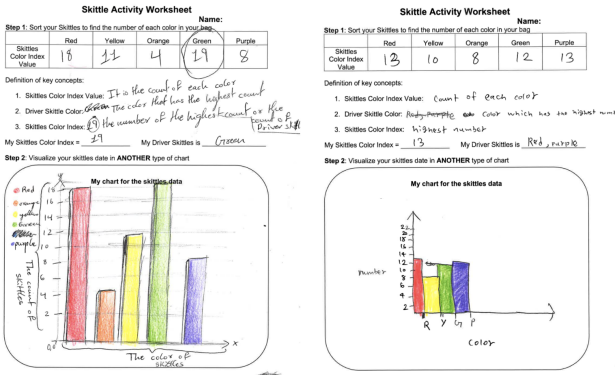

Figure 4: Sample worksheets for Step 1 and Step 2 completed by students.

Figure 5: Students reorganized Skittles from a bubble chart into a bar chart.

4 Implementation

In this section, we describe the steps of the activity, as well as our experience of the implementation of this activity in the Data Visualization and the Environment (DVE) summer camp [9, 10] about data visualization with middle school students from a local Atlanta-area school in the summer of 2025. The activity was conducted on the second day of the summer camp, and lasted for 60 minutes with 18 middle school students. The first author primarily led the activity, with the middle school teacher and the research team providing facilitation. The worksheet we used in this activity is included in the supplemental materials.

4.1 Step 1: Finding the SCI

Students were given a bag of Skittles and asked to organize the candies in a way that helped them find the count of each color in their bags of Skittles, which they recorded in their table. We then established the metaphor of the Driver Skittle Color, the color that has the highest count, and Skittle Color Index (SCI), the count of the Driver Skittle Color (see the Skittles column in Figure 3). Students were asked to write down their definitions of these concepts in the worksheet and also find the Skittle Color Index and Driver Skittle Color of their dataset (see Step 1 in Figure 4). Specifically, as students organize their Skittles into structures—most often clusters similar to bubble charts—we prompted a discussion on whether their arrangement was effective in finding the SCI and Driver Skittle Color. We believed this would transition naturally into the DPV framework, particularly emphasizing the Purpose dimension: What type of "big idea" are you trying to communicate with your visualization? At this point, students shared how they would use the DPV framework to explain the chart they had constructed.

4.2 Step 2: Visualizing Skittles

Students were then challenged to create a sketch with their Skittles data in a different structure than how they organized their candies in Step 1 to convey a different kind of "big idea" —whether it be comparison, composition, distribution, or relationship— as Purpose in the DPV framework (see Step 2 in Figure 4). Figure 5 shows an example of students reorganizing their Skittles from a bubble chart style into a bar chart style before they created the sketch on the worksheet. After completing their visualizations, students shared their reasoning for their design choices and reflected on how their new representation was similar to or different from their previous Skittles organization. We designed this step to help students recognize how design choices can support different "Big Ideas," to address LO3.

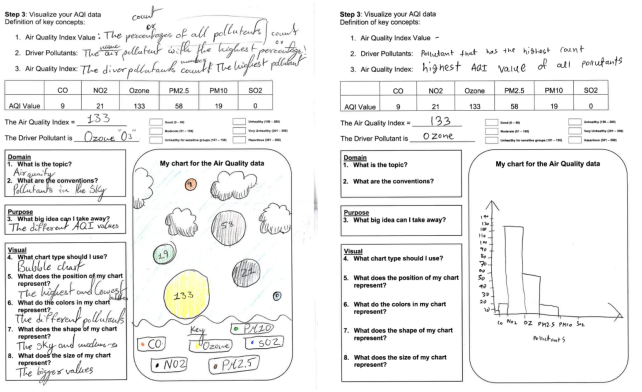

Figure 6: Sample worksheets for Step 3 completed by students.

4.3 Step 3: Visualizing AQI

Once students had practiced through this tangible activity to internalize the concept of SCI and Driver Skittle Color, we transitioned to the AQI concept. We used the bag of air as a metaphor and connected it with the bag of Skittles to model the different pollutants in the air. Then, we prompted students to explain how we could borrow the definitions of Driver Skittle Color and Skittle Color Index to define the Driver Pollutant and Air Quality Index (see the Air Quality column in Figure 3). We described the Driver Pollutant as the pollutant with the highest AQI value, and Air Quality Index as the AQI value of the Driver Pollutant. With this conceptual bridge in place, students were introduced to a real AQI dataset in Atlanta with six different pollutants. Drawing on their Skittle-based visualization experience, students were then asked to go through the DPV framework again and sketch a data visualization that could help others identify the AQI and Driver Pollutant of the day (see Step 3 in Figure 6). At this point, instead of using Skittles' flavors to color the bars, we introduced students to the AQI color scale [5], which ranges from green (good, 0-50) to maroon (hazardous, 301-500), along with the actual AQI value of each pollutant.. This step was intentionally designed to help students practice creating data visualizations using the DPV framework, with the aim of addressing LO4. Through this scaffolded transition from Skittles to real-world air quality data, we hypothesized that students would develop a grounded understanding of how AQI is constructed and practice choosing effective data visualization designs to support different communication goals.

5 Students' Experience Evaluation

In this section, we describe our data collection and analysis method to assess how students' experiences were derived to understand whether the curriculum is effective in achieving the learning objectives.

5.1 Data Collection and Analysis

This IRB-approved study was conducted with the consent/assent of parents/guardians, students, and teachers. 17 out of the 18 students consented to participate in the study (average age = 12.3, 7 identifying as women/girls or non-binary). We conducted an observation of students' experiences and collected students' worksheets. 15 copies of worksheets were collected (two students lost their copies). The activity session was also video recorded.

As an informal summer camp activity, we did not conduct any formal assessment of students' learning outcomes. Instead, we analyzed students' worksheet responses on their understandings of the Driver Pollutant and Air Quality Index definitions and the charts they created for the Skittles data and AQI data. We also reviewed our observation notes with the research team to understand how students engaged during the activity.

5.2 Students' Engagement

The decision to use tangible candies for this activity was driven by the desire to have a fun activity to keep students engaged during the full-day summer camp. Students showed enthusiasm for using Skittles to learn air quality concepts and data visualization, actively sharing their thoughts on what data could be extracted from a bag of Skittles. During activity Step 1: Finding the SCI, students who had previously shown low engagement in other activities appeared more engaged when organizing their Skittles, as they discussed their Skittles organizing strategies with peers, and compared counts. This suggests that using tangible candies such as Skittles can be an effective way to engage students in a science-related activity, especially as an introduction to capture students' attention.

5.3 Learning Objectives on Air Quality

The activity aimed to help students learn the definitions of the Driver Pollutant (LO1) and the AQI (LO2). In activity Step 1: Finding the SCI, the task of identifying the color with the highest count appeared intuitive to students: even before we introduced the concepts of Driver Skittle Color and Skittle Color Index (SCI), we observed that students were already initiating conversations with their peers about which color had the highest count and the actual number in their own bags. This demonstrates the effectiveness of the Skittle Color Index (SCI) concept as an entry point for introducing the structure and logic behind the Air Quality Index (AQI).

In activity Step 3: Visualizing AQI, where we transitioned from Skittles to air quality, we observed that during the in-activity discussions, most students were able to self-derive the definition of Driver Pollutant following the definition of Driver Skittle Color with relative ease, but many struggled to grasp the definition of the Air Quality Index from the Skittles Color Index, requiring additional prompts by the team to make the connection. This suggests that additional scaffolding is needed to help students connect the concepts of Driver Pollutant and AQI.

During activity Step 3: Visualizing AQI, on the worksheet (see Figure 6, students were asked to write down their definitions of Driver Pollutant and Air Quality Index. In their worksheet responses, all students were able to define Driver Pollutant as the pollutant with the highest amount and Air Quality Index as the AQI value of the Driver Pollutant. Students were also provided with a dataset with six pollutants and their Air Quality Index Values for a day, and were asked to find the Driver Pollutant and the Air Quality Index of the day. Out of the 15 students' responses collected, all of them correctly identified the Driver Pollutant and Air Quality Index of the day. The analysis results of these two tasks show that students were able to correctly define and identify the Driver Pollutant and the AQI of the day, addressing LO1 and LO2.

5.4 Learning Objectives on Data Visualization

The activity aimed to help students practice choosing appropriate chart types for different "big ideas" (LO3) and creating a data visualization of a real-world air quality dataset following the DPV framework (LO4). During activity Step 1: Finding SCI, we observed that students were also able to naturally connect the structures they created with their Skittles to familiar chart types. For example, when prompted to explain their Skittles arrangements using the DPV framework, we observed that many students recognized that the shapes they had formed resembled bubble charts. This demonstrated the effectiveness of using Skittles candies as a tangible medium for constructing and recognizing data visualizations. Activity Step 2: Visualization Skittles was also effective in inspiring a variety of design ideas: on the worksheet (see Figure 4, students created various charts to represent their Skittles Data, including nine bar charts, three pictogram bar charts, one pie chart, one tree map, and one T-chart. Students also verbally shared their reasoning behind chart type selection and design choices. These discussions reflected their understanding of how the same dataset can be approached from different perspectives to answer diverse questions. Comparing the Skittles charts created in Step 1 and the visualization sketches created in Step 2 shows that students were able to create different types of charts for different types of "big ideas", addressing LO3.

During activity Step 3: Visualizing AQI, students were asked to create a sketch for the Air Quality data following the DPV framework (see Figure 6). Among the 15 collected responses, students produced 10 bar charts, two bubble charts, and three pie charts to represent the dataset. 13 charts accurately depicted the AQI data, providing evidence that this activity supported LO4 by guiding students to apply the DPV framework to visualize a real-world AQI dataset.

6 Discussion

In this section, we described the limitations and challenges we identified during the activity that open up opportunities for future research. We also shared an extension of the activity for more advanced learner groups.

6.1 Challenges and Future Directions

Through observing the activity, we also identified some challenges existing in the curriculum. For example, first, in activity Step 1: Finding the SCI, some confusion arose around two terms—Driver Skittle Color and Skittle Color Index—as students often mixed up which referred to the color and which to the numeric value. As the terms are manufactured entirely for this activity and have no external value, we are exploring ways of providing clearer resources distinguishing these terms and, more importantly, connecting them to the air quality terms, especially considering the trade-off between the time and efforts allocated to the Skittles-related terms and air quality-related scientific concepts.

Second, in activity Step 3, when transitioning from Skittles to the air quality context, the fact that the colors in a bag of original flavor Skittles are the same as those used in the AQI scale caused some confusion. We attempted to clarify that the Skittles activity used color to signify qualitative categories when mapping different Skittles colors to pollutant types, while the AQI portion of the activity used colors to distinguish quantitative values (e.g., green means lime-flavored Skittles but "good" air quality below 50 on the scale). This could lead to a misunderstanding of how AQI color codes are derived from pollutant values. Therefore, it is crucial to use precise

language when drawing analogies between Skittles and air quality to clarify both the parallels and the distinctions.

Working with food can also raise some concerns. For instance, some students and teachers may prefer not to use food due to potential allergens, religious restrictions (such as the use of gelatin), concerns about food waste, or the possibility of attracting insects. In our activity, Skittles were selected for their accessibility and playful nature, which fit well with the summer camp context. However, other materials—such as LEGO bricks, colored paper cutouts, or pebbles in different shapes or colors—could also serve as suitable alternatives.

Although we did not formally measure students' engagement or the learning outcomes of the activity, in-activity observations and analysis of students' artifacts indicated that the playful and tangible nature of Skittles helped sustain engagement and create an effective learning experience. As part of the 10-day summer camp, students' learning outcomes could also be indirectly evidenced by their ability to apply the DPV framework in subsequent activities and to create more complex visualizations using authentic datasets. Future iterations of the activity could incorporate more systematic measures—such as pre- and post-activity surveys and students' performance in the following activities—to explicitly evaluate the intended learning outcomes.

Despite these challenges, this activity also revealed opportunities to foster other data literacy skills as required for modern society [17]. For instance, prompting students to consider how they handled irregularly shaped Skittles—whether they discarded them, counted them as half, or ignored them—highlighted the role of human decision making during the data collection process, aligning with themes that have been recently discussed in data humanism [11]. Future iterations will address the challenges identified above and further explore the broader educational potential of using constructive visualization activities to teach science concepts through data visualization.

6.2 Future Extension: Visualizing AQI trends

The original activity can be further extended into a more advanced topic of comparing the trend of AQI across multiple days, which might be suitable for a more advanced student group or a more extended activity session. After students reorganize their skittles into different types of charts, we would further challenge them by asking, "What if we put all the bags together?" We suggest students could form into groups of 4-6 and pool their Skittles data to create a larger, more complex dataset. Each group would be assigned a new guiding question (e.g., "What made up all the four bags?", "What is the SCI of each bag?", or "What is the distribution of each color across bags?"), pushing them to think aggregatively about their data. This would further transition into a real AQI dataset that included multiple days' entries with AQI values for all six pollutants (see Figure. 7). Drawing on their Skittle-based visualization experience, students can be asked to go through the DPV framework and sketch up a data visualization to determine the trends of AQI values and driver pollutants. In future work, we aim to explore how such scaffolded transitions—from tangible, playful data modeling to authentic environmental datasets—can support students' deeper understanding of temporal trends and their implications for air quality decision-making.

7 Conclusion

The Skittles activity demonstrates how playful, tangible materials such as Skittles candies can effectively support middle school students in understanding data visualization principles and foundational air quality concepts. Grounded in principles of constructive visualization, the activity helped students engage with the abstract structure of the AQI through hands-on exploration and design reasoning. By integrating the DPV framework and facilitating multiple rounds of co-design and iteration with researchers and K-12 teachers, we ensured the activity was developmentally appropriate, pedagogically sound, and adaptable for learning settings in K-12. Our implementation experience and student responses suggest that tangible activities like this can support conceptual understanding and make data literacy more accessible and engaging. We see this activity as one promising example of how engaging, constructivist approaches can lower the barrier to data visualization literacy education and support a broader vision of making data visualization design approachable to all learners.

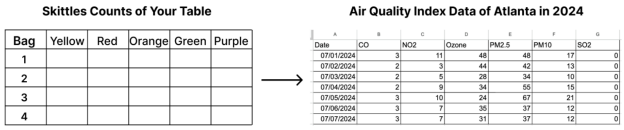

Figure 7: The advanced extension of the activity that connects Skittles data to AQI data over multiple days.

Supplemental Materials

The worksheet used during the activity was included in the supplemental materials.

Acknowledgments

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