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Learn, Prepare, Act: "Throwing Shade" on Climate Change

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ABSTRACT
Science and technology centers continue to emerge as hubs for building climate change and resiliency literacy in communities around the United States. What's less clear, however, is how these institutions foster and sustain climate action based on this acquired literacy. The Science Museum of Virginia developed, delivered, and evaluated climate science and resiliency-themed programming over a three year period, connecting with audiences from "K to grey." Hyper-localization of climate change, accomplished by leading a small-scale community-based participatory research campaign (also known as "citizen science") to assess the City of Richmond's urban heat island effect, improved audience literacy and recall of adaptation and resilience solutions. When further nested within curriculum aligned with the National Oceanic and Atmospheric Administration's Steps to Resilience Framework, hyper-localization produced additional learning and behavioral outcomes that bridged the gap from literacy to action. We posit that our model can inspire similar adaptation and resilience action-oriented programs in urban areas around the country.

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Human-caused climate change amplifies the likelihood and intensity of environmental stressors like extreme heat and heavy precipitation, and is increasingly linked to worsening extreme events like droughts and wildfires.[1] As such, human-caused climate change presents a mounting challenge to communities across the world as these stressors affect human health and safety, urban and rural infrastructure, food security, and water availability. This, in turn, exacerbates existing inequities in the present-day while threatening the future economic growth in resource-limited communities.

Resilience in the face of climate change then is the ability of a system (e.g. an organization, a family, a neighborhood, a city, a country) to prepare for and absorb the impact of these amplified stressors, retain the continuity of essential functions during and following an extreme event, and then return to or even exceed baseline functionality in the aftermath of an event. Examples of climate change resilience in the context of a family might be (1) having a plan for lines of communication among family members before, during, and after an extreme event (e.g. lowered sensitivity to an extreme event) (2) having adequate amounts of food, water, medicines, and other necessary items to survive for several days after the event (e.g. improved adaptive capacity) and/or (3) having the knowledge of and access to safe, reliable shelter and/or resources should personal preparedness efforts fall short or fail (e.g. limiting exposure).

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However, in order to achieve the family-based example of climate change resilience outlined above, it is critical for those within any system to first understand the climate stressors that affect their region (e.g. hurricanes, droughts, extreme heat waves), the options available to address the system's exposure and sensitivity to those stressors (preparedness kits, local programs to expand green infrastructure, public cooling centers, etc.), and the adaptive capacity within the system that can limit the negative impacts of those stressors (such as their physical distance from an evacuation shelter or availability of central air conditioning). Framing climate resilience in this literacy-first context, it is vital to provide educational experiences for public and stakeholder audiences to discover the ways worsening climate stressors impact their daily lives as well as the options they have in order to take adaptive action to build resilience to these changing environmental stressors. While this article does not specify which actions individual urban areas should take, it does instead describe a framework through which to co-develop a strategy that fits the needs of your institution, community partners, and stakeholders alike.

Science and technology centers as hubs for climate resilience

Since 2005, the Environmental Literacy Program (ELP) within the Office of Education at the National Oceanic and Atmospheric Administration (NOAA) has consistently provided a federal funding source meant specifically for building capacity in informal science education centers to develop museum exhibitions, K-12 curricula, online educational resources, citizen science opportunities, civic engagement events, and out-of-school programs meant to inspire the public and stakeholders to use earth systems science to foster environmental stewardship and advance climate resilience.

The Science Museum of Virginia was awarded an ELP grant in 2015 focused on achieving several educational outcomes (our "impact framework") related to building literacy for climate change resilience but with the ultimate goal of empowering our audience to use science to take action and build resilience to climate change (Figure 1). Our program structure relied on connecting with our target audiences both in person as well as remotely, with experiences being offered within the museum's day-to-day operations (such as several free lecture series, public hands-on workshops, daily and repeated facilitations using the NOAA Science On a Sphere, daily screenings of an in-house large format screen film) and complementary opportunities for continued engagement after guests would leave. These museum-external experiences relied on generating and sharing social media content and infographics, developing citizen science projects, producing video and audio programs, and building new collaborations with local nonprofits to do place-based experiences.

Formative evaluation of our programming[2] showed that many of our early programming choices were, frankly, missing the mark for achieving our impact framework's goals. Many of our initial programming activities simply were not connecting the impacts of global climate change to our (adult) audiences' daily experience in any meaningful way, and certainly not then promoting the adoption of individual types of resiliency actions. These resiliency actions were weighted toward climate adaptation instead of mitigation strategies (i.e. our programming focused primarily on actions that would prepare our audience for the impacts of climate change, instead of focusing on strategies that

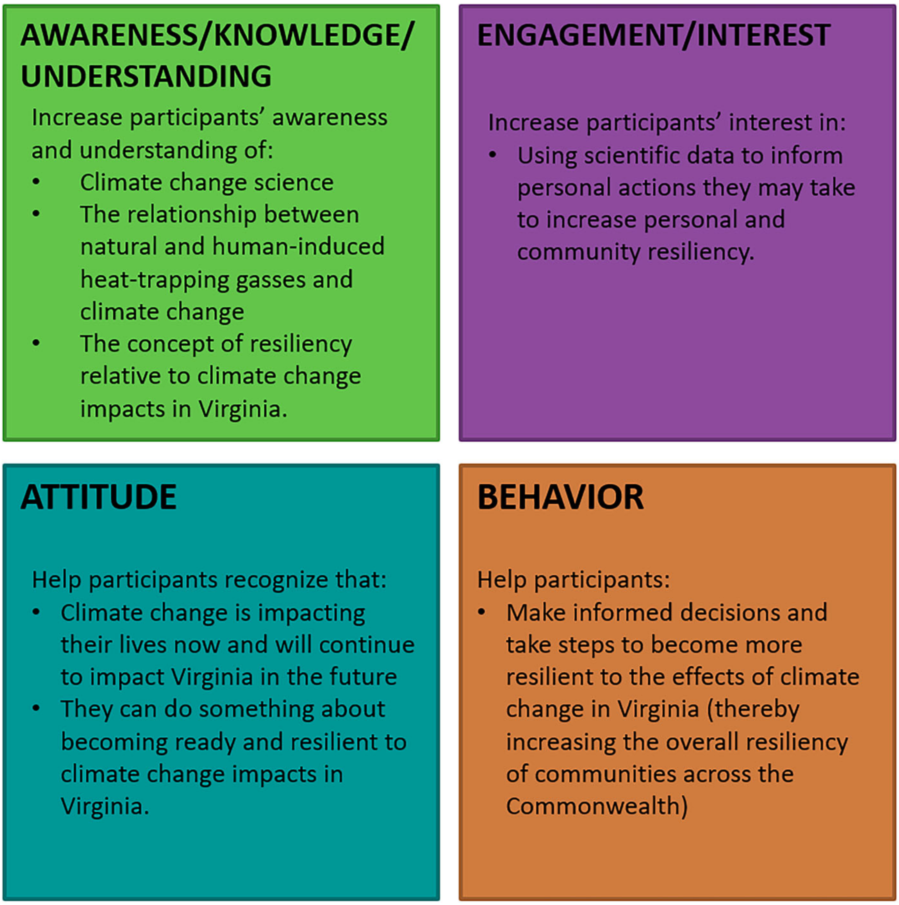

Figure 1. The Science Museum of Virginia's Impact Framework for measuring success in our climate change and resiliency programming. The Education Outcomes Impact Framework was developed using the National Science Foundation's Framework for Evaluating Impacts of Informal Science Education Projects as a guide. Reproduced from RK&A, 2018.

reduce the total amount of climate change into the future by curbing emissions of heat-trapping gases). For example, evaluated adults were remembering aspects of our native bee habitat building experience, such as how bee populations are declining, but were unable to connect that to a local resiliency action or even climate change more generally. Clear links between several programs' content and resiliency actions were unfortunately missing. We then chose to explore how we might modify and adjust our programming or come up with entirely new experiences that would connect climate change to locally-relevant issues, following climate change communication research and guidance from the Center for Research on Environmental Decisions.[3] The question was, how best do we accomplish this?

In order to achieve this hyper-localization of climate change, we needed to go beyond what we had proposed in our original NOAA work to include what we're now calling a "community-collaboratory participatory research campaign" to assess extreme urban heat in Richmond.

Community-collaboratory participatory research campaigns

In recent decades, community-based participatory research programs (widely known as "citizen science") have been used to investigate all manner of environmental conditions and biological phenomena, significantly expanding our understanding of various phenological events in birds and insects,[4] extents of present-day nuisance flooding on astronomically high tide days in order to evaluate flood models,[5] and urban air quality[6] in our changing climate.

Most importantly, community-based participatory research has been widely recognized for its ability to develop community science literacy and create opportunities for marginalized groups to collaborate with scientists and science communities.[7] As climate change is already and will continue to disproportionately impact those from historically marginalized communities in the U.S.,[8] achieving equitable climate resilience in the U.S. therefore requires the centering of these specific communities in efforts to build resilience. Thus, ensuring that we intentionally recruited, included, and promoted the involvement of organizations and individuals from marginalized communities formed the nexus of our community-based participatory research program and has since created our idea of a "community-collaboratory participatory research campaign" (CCPRC).

An emerging, scalable vehicle-based methodology for assessing how extreme heat events are amplified within city landscapes (also known as urban heat islands) lends itself particularly well to developing and executing community-collaboratory participatory research campaigns, mostly due to the limited amount of training time needed for the scientists to effectively make reliable measurements as well as feel capable and ready to conduct the traverses.[9] Community partner organizations and volunteers collaborate with scientists, educators, and policymakers to design pre-determined driving routes that pass through the largest variation in land use/land cover across the urban area. This approach increases the likelihood of observing maximum land use-controlled temperature variance within the urban area. This vehicle traverse method also incorporates nearly "fail-safe" technology that community partners can use reliably, and further makes use of commonly familiar mapping software (e.g. Google Maps) to direct the community partners along consistent "traverse" routes that they follow with their own (or lent) automobile. By actively engaging organizations that were already active in various neighborhoods around Richmond where we did not already have a long-time institutional footprint, our project was able to assign community partners who were already familiar with landscapes and neighborhoods to those areas. Accessing this place-based knowledge allowed us to target specific land use types that may be a community landmark or gathering place, or may be undergoing significant greening or revitalization, thereby increasing our ability to transfer our findings to human-level exposure to extreme urban heat and actions necessary to reduce that exposure. It also allowed the participants to feel like they had true ownership of the methodology, however limited it was.

Community-collaboratory volunteers collected data during one-hour traverse times at 6:00AM, 3:00PM, and 7:00PM to achieve a description of the climatological coolest, hottest, and early evening temperatures throughout the day across their traverse areas. In total, we collected over 100,000 measurements of temperature during our campaign in Richmond, VA.[10] In a case of classic scientific serendipity, we were fortunate to make our observations during a major heat event that occurred on July 13 2017. With maximum air temperatures reaching 99°F at the Richmond International Airport and record-breaking average (88°F) and minimum temperatures (77°F), we had the "perfect" weather to understand how our city's structures would either strengthen or mitigate heat extremes and get a "look into the future" of a more extreme warm season.

Our results identified an approximately 16°F difference between the warmest and coolest places in Richmond during the hottest time of the day (3–4PM[11]). The coolest places had lots of dense shade and plants while the hottest places were post-industrial neighborhoods with very little tree cover, wide streets, and low-slung buildings. Most of these places also remain at significantly elevated temperatures well into the evening (7–8PM).

These data and maps showing tree canopy and impervious surface amounts then formed the basis of our updated climate change and resiliency facilitated hands-on experience and workshop, "Preparing for a Hotter, Wetter Virginia," and have the ability to connect the idea of local-scale climate change with everyday experience as well as backyard adaptation solutions, as we describe below.

From data to action: summative evaluation

Summative evaluation of the core aspects of our modified and localized climate and resilience programming showed that, by and large, we achieved the desired educational impacts of affecting our audience's awareness, engagement, attitude, and behaviors related to climate change and resilience[12] (Figure 2(a)). However, we also learned a great deal about how each of our individual activities were either relatively stronger or weaker than others when qualitatively scored along two major axes – the Y-axis representing their ability to communicate climate science concepts (literacy) and the X-axis representing their ability to communicate personal resilience behaviors (action) weeks following the experiences (Figure 2(b)).

The activities that relied most heavily on the facilitated presentation of climate science data and visualizations performed the best to communicate climate science but were relatively less skillful in communicating climate resilience behaviors (e.g. Science On a Sphere facilitated presentations, Cosmic Climate Cookbook large format film). Meanwhile, those activities which sought to promote the deepest opportunity for hands-on engagement in the science of climate change and its impacts performed the best to promote climate resilience behaviors but were relatively less skillful in communicating the underlying climate science (e.g. Extreme Event Challenge, a public role-playing workshop, and Ready Row Homes, a hands-on green infrastructure modeling interactive). The Ready Row Homes activity (the interactive, hands-on part of the facilitated climate and resilience program, "Preparing for a Hotter, Wetter Virginia") was overall the highest-performing activity averaged over both categories (Figure 2(b), top right). The underlying mechanics for the Ready Row Homes experience were based on the related activity developed at the Philadelphia, PA-based Franklin Institute which designed them as part of its National Science Foundation-funded Climate and Urban Systems Partnership program.

The "Preparing for a Hotter, Wetter Virginia" experience (which also incorporates open-ended hypothesis generating and lecture-style sharing of data and other visualizations) focuses on communicating green infrastructure adaptation solutions to the two

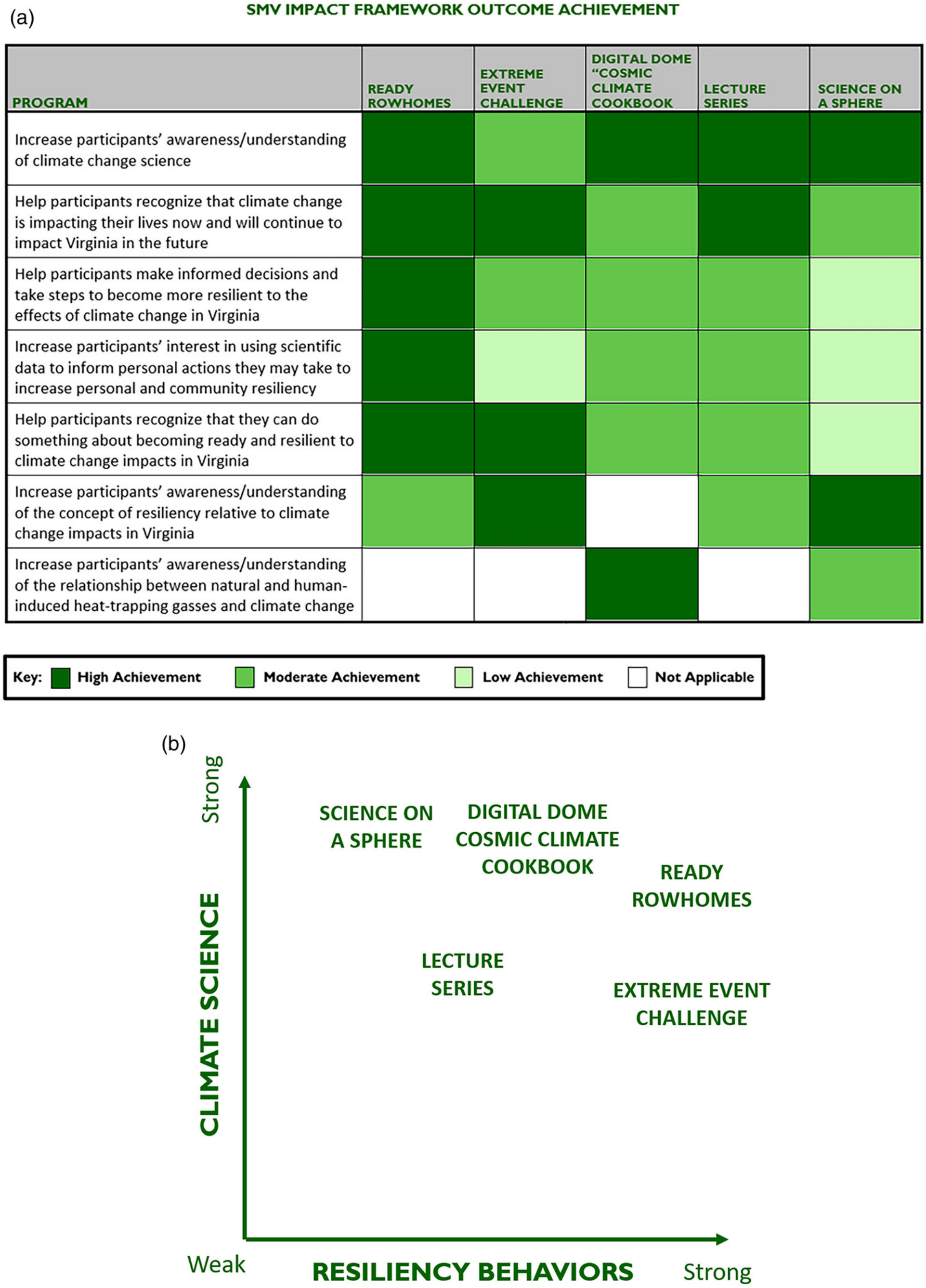

Figure 2. (a) "Heatmap" of Science Museum of Virginia's Education Outcomes Impact Framework achievement by climate change and resiliency program (top row). Darker greens represent qualitatively higher achievement in educational outcomes than lighter greens. Some programs did not touch on specific content areas or were not evaluated for their particular strength or weakness for that content stream, and are left white. (b) Cartesian representation of Impact Framework achievement by program, whereby "up" (on y-axis) or "out" (on x-axis) means qualitatively stronger educational outcomes. The individual programs are listed to represent the core of the experience.

primary environmental stressors experienced in a city in central Virginia: namely, the worsening heat extremes and urban heat island effect, or the phenomenon whereby human structures amplify heat in urban areas, as well as increased stormwater runoff during intensifying precipitation events. In our variation of this activity, we first introduce our participants (on the museum floor, this could be anyone "K to Gray," but in the case of our evaluated audience, they were adults 26–53 participating in an urban gardening class, see below) to climate data and visualizations that show increasing trends in both extreme heat and precipitation events in the City of Richmond and throughout the Commonwealth of Virginia. Then, we interpret curated map-based visualizations of citizen science-derived urban heat island data for the City of Richmond (described in more detail below), locations of combined sewer overflow systems, and areas of extensive impervious surfaces (asphalt and cement, which funnel instead of filter runoff into our aging stormwater infrastructure). All of these city-specific structures work to make us more vulnerable to climate change, as they magnify the already worsening background conditions of our weather extremes. Using these data as a climate science concept framework, participants are then led through two team-based design challenges.

The first challenge implores participants to minimize the surface temperatures while the second encourages them to minimize stormwater runoff on these manufactured Ready Row Homes (Figure 3). Participants explore and evaluate the impacts of their incremental designs by experimenting with different arrangements of model-based representations of real-world solutions to extreme heat and precipitation. In this way, participants use sponges, 3D-printed rain barrels, green-colored buffer pads with 3D-printed elevating "trunks," and replacing dark surfaces with reflective surfaces to explore these model-based representations of real-world adaptation solutions to extreme precipitation and heatwaves. Participants learn to use infrared thermometers and FLIR thermal cameras to scientifically measure their heat designs (Figure 3(a)) while a rudimentary "stormwater sewer" placed under a small drain in the street allows guests to see how much stormwater is retained by their designs (Figure 3(b)). Generally, but not always, these experiments with design strategies are then recreated in the real world by physically heading outdoors to take infrared temperature measurements and images of various surfaces, visiting and testing the museum's own stormwater best management practice structures, and/or building a real rain barrel to take home to install on their own houses.

One of the primary strengths of the Ready Row Homes activity was that it provided clear, at-home examples of climate change adaptation strategies. Transforming this global issue into a backyard solution was particularly useful to our evaluated respondents. Participants also reflected on how this made them feel like they could know what to do right away and start the journey to climate resilience.[13] Part of this feeling of empowerment was tied to the presentation of the localized urban heat island effect in Richmond, which changed the impacts of climate change from something big and global to something manageable and local. Our evaluation of this audience (five telephone interviews of the fourteen 26–53-year-old adult individuals in the Lewis Ginter Urban Gardeners class) asked nine questions about their feelings about the program as well as recall information related to the content of the experience.[14] By and large, this program accomplished the highest achievement in our impact framework (Figure 2(a,b)).

a

b

Figure 3. (a) Children and adults use infrared thermometers to measure various surface temperatures during a Ready Row Homes facilitation during a special event at the Science Museum of Virginia. These measurements are paired with locally-relevant maps (background) to show similar patterns of urban heat island phenomena alongside treeless and heavily paved areas. (b) Adult audience use watering cans as extreme precipitation on the Ready Row Homes to understand how green infrastructure (sponges, foreground) can be used to absorb and retain stormwater during a “Preparing for a Hotter, Wetter Virginia” facilitated program.

The question then became how do we translate this experience into a longer-term, targeted program for sustained and equitable climate action? We turned back to our community-collaboratory partners to answer this question.

From vulnerability to action: Throwing Shade in RVA

After the completion of the Richmond urban heat island assessment, and concurrent with our ongoing NOAA programming, our community-collaboratory participatory research campaign partners collaboratively developed Richmond's first "heat vulnerability index map," recognizing that elevated ambient air temperatures alone do not necessarily relate directly to acute heat vulnerability and that some areas of our city might need to be prioritized for action due to an excess of vulnerability. Studies have shown that urban heat disproportionately impacts those communities with pre-existing health conditions (e.g. chronic obstructive pulmonary disease, asthma, cardiovascular disease, etc.), limited access to resources, and the elderly.[15] As a first estimate to identify those communities more vulnerable to heat, we combined the urban heat island data (or the direct human exposure to extreme urban temperatures) with other socioeconomic and environmental variables that might represent sensitivity to higher heat (the balance of tree canopy to impervious surface extent) and adaptive capacity to extreme heat (in this case, we use the percentage of families in poverty in an American Community Survey census block group) by feature scaling and summing them at the census block group level. The derived index, then, could range from 0 (not at all vulnerable to heat) up to 4 (extremely vulnerable to heat) on the basis of these four variables (Figure 4). While this does not include health-related information explicitly, studies of the City of Richmond have also shown strong correlations between socioeconomic status and negative health outcomes.[16] As such, we assume that by including the percentage of families in poverty, we might capture specific health-related aspects of heat vulnerability.

Once we completed the vulnerability index map, we distributed it among our community partners. We focus here on the outcomes of one such continued collaboration with community-collaboratory participatory research partner Groundwork RVA, a nonprofit that engages Richmond public high school teenagers to transform blighted spaces into public assets through community-based greening strategies. Groundwork RVA's headquarters is located within and directly serves a large cluster Richmond census block groups with the highest vulnerability to extreme heat.

With Groundwork RVA, the Science Museum of Virginia piloted a teen-focused informal education program in Spring 2018. The program, which we named "Throwing Shade in RVA," sought to empower Richmond youth to get involved in building resilience to extreme heat by using the urban heat vulnerability index as a guide to greening up and shading one of Richmond's hottest and most vulnerable neighborhoods–right where Groundwork RVA is headquartered and where many of the teens live. Seventeen Richmond Public Schools teenagers (age 14–18, 8 males, 9 females) participated in the pilot project which occurred one afternoon a week for three hours a day over a six week period. The Groundwork RVA teens were paid a stipend for their participation in the program. Several of the Groundwork RVA teen volunteers who volunteered for the

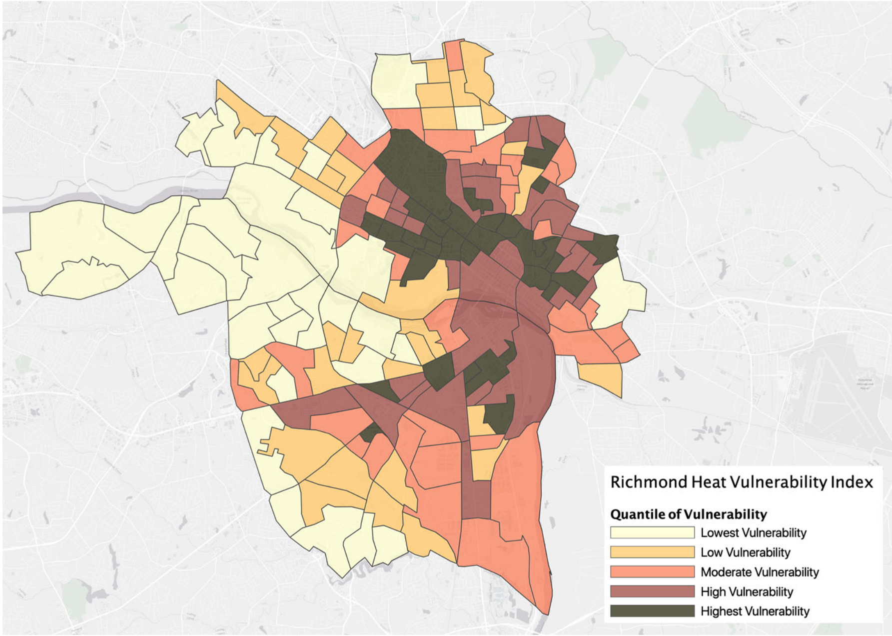

Figure 4. Richmond's first co-developed heat vulnerability index map by equal-count quantile. Deeper reds indicate higher vulnerability as estimated from census block group-average tree canopy availability, impervious surface expanse, temperature exposure, and families in poverty. These categories were collaboratively chosen by campaign partner organizations.

urban heat island CCPRC were also participants in this museum-conducted Throwing Shade pilot program.

We framed the Throwing Shade program's curriculum around NOAA Climate Program Office's Steps to Resilience[17] which gives explicit steps toward building resilience to climate stressors, in the following ways:

(1) Explore Hazards – the Groundwork RVA "Green Team" teenagers explore the urban heat island map and data, including long-term climate warming trends using the NOAA Climate Explorer.[18] The teens form teams that seek to answer (1) Are heat waves becoming more intense (yes, by how much?), (2) Are heatwaves expected to get more intense (yes, by how much?), and (3) Do heatwaves impact people in Richmond differently (yes, which areas?).
(2) Assess Vulnerability and Risks – Green Team then explores the data that underlie the Richmond urban heat vulnerability index by census block group, comparing the index to exposure to extreme urban heat. This discussion also considers long-term impacts of historical land-use policies like redlining (the practice of systematically denying communities of color access to real estate loans during the New Deal) to determine the equitable representation of vulnerability. Students answer questions related to who lives in these neighborhoods and how do we best represent their wishes in building climate resilience.
(3) Investigate Options – Green Team then explores the many different solutions to the urban heat island effect using the EPA urban heat mitigation toolkit[19] and the Science

Museum of Virginia's "Preparing for a Hotter, Wetter Virginia" hands-on facilitated experience. Teams design the "coolest" Ready Row Home using 3D-printed shade trees and green sponges acting as green infrastructure like green roofs and bioretention rain gardens. Teams design some adaptation solutions for the surrounding neighborhood based on what they've discovered.

(4) Prioritize and Plan – Green Team then decides which solutions make the most sense (and have maximum co-benefits) based on a very limited project budget and time to implement the project. Teams choose one project from both teams and vote for the one they'd like to implement in the following two weeks.

(5) Take Action – Green Team implements their prioritized action. In Spring 2018, this was to plant rapidly-growing pear fruit trees at a nearby high school's campus. The "co-benefits" of this resilience option were fresh food and air quality improvement, while the primary benefit was long-term shading for kids using the playground who needed to rest.

The pre- and post-program participant evaluation surveys identified significant increases in the teens' self-assessed confidence in understanding the drivers, societal impacts, and adaptation solutions to the urban heat island effect, even if they had previously engaged in the CCPRC ($n = 17$, effect size 5.4 points on a 0–10 rating scale, p-value <0.001, 95% confidence interval 4.2–6.4 points). These evaluation surveys also included open-ended questions in the form of providing definitions to particular words. Pre- and post-program comparisons identify increases in the complexity of the words the teens used in their self-described definitions of "urban heat island" (36% increase in syllables used per word, 128% increase in unique words used, Figure 5). While this program was not formally evaluated by our third-party evaluation firm, these results give us confidence that "Throwing Shade in RVA" can serve as a model for how community partners and informal science centers can collaborate on climate education programs for community impact and building resilience to climate stressors. Groundwork RVA and our other CCPRC partners were instrumental in connecting the Science Museum's mission to previously underrepresented and nontraditional museum audiences. By choosing to coordinate a CCPRC with input from community organizations that might benefit from the results of the CCPRC, a museum can truly transform its impact.

Throwing shade in your community

Taken together, the results of our NOAA programming and its derivatives have shown that by localizing climate change, and framing programming with this local lens,[20] many of the aspects of our specific impact framework related to climate change and resiliency literacy can be achieved (Figure 2(a,b)). Moreover, creating localized datasets by empowering community-collaboratory participatory research campaigns can then be leveraged to inspire large, measurable educational outcomes related to vocabulary and confidence in scientific knowledge (Figure 5). Furthermore, it can produce long-lasting activation in the climate action space for systematically marginalized communities, as we have seen with multiple projects undertaken by other boundary organizations since our CCPRC was completed. As climate change continues to disproportionately impact historically marginalized communities, it is imperative that we as a STEM informal

Figure 5. (a) Pre-Throwing Shade evaluation word clouds generated from all responses to the open-ended question "Define, in your own words, the 'Urban Heat Island Effect' and Its Impacts on Richmond Communities" (*n*=17). (b) Post-Throwing Shade evaluation word clouds generated from all responses to the open-ended question "Define, in your own words, the 'Urban Heat Island Effect' and Its Impacts on Richmond Communities" (*n*=17).

education field embrace the centering of these communities in our outreach and more importantly in our co-creation of datasets relevant to the everyday experiences of our audiences, especially if we continue to focus our attention on climate change and resiliency topics.

Notes

1. National Academies of Sciences, Engineering, and Medicine, *Attribution of Extreme Weather Events in the Context of Climate Change*.
2. RK&A, Inc., "Formative Evaluation."
3. Center for Research on Environmental Decisions. "The Psychology of Climate Change Communication."
4. Hurlbert and Liang, "Spatiotemporal Variation in Avian Migration Phenology," e31662.
5. Loftis et al., "Validating an Operational Flood Forecast Model Using Citizen Science in Hampton Roads, VA, USA," 242.
6. Constant, "The Role of Citizen Science in Air Quality Monitoring."
7. National Academies of Sciences, Engineering, and Medicine, *Learning Through Citizen Science*.

8. Pincetl et al., “Urban Heat Stress Vulnerability in the US Southwest.”
9. Voelkel et al., “Developing High-Resolution Descriptions of Urban Heat Islands,” 160099–6, doi:10.5888/pcd13.160099; Shandas et al., “Integrating Satellite and Ground Measurements for Predicting Locations of Extreme Urban Heat,” 5–13.
10. ibid.
11. ibid.
12. RK&A, Inc., “Summative Evaluation.”
13. ibid.
14. ibid.
15. Hess et al., “Summertime Acute Heat Illness in U.S. Emergency Departments From 2006 Through 2010,” 1209–15; Madrigano et al., “A Case-Only Study of Vulnerability to Heat Wave–RelatedMortality in New York City (2000–2011),” 672–78.
16. VCU Center on Society Health, “Health Equity in Richmond, Virginia.”
17. NOAA Climate Program Office, “Steps to Resilience.”
18. ibid.
19. U.S. Environmental Protection Agency, “Heat Island Cooling Strategies.”
20. Center for Research on Environmental Decisions, “The Psychology of Climate Change Communication.”

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Bibliography

Center for Research on Environmental Decisions. *The Psychology of Climate Change Communication: A Guide for Scientists, Journalists, Educators, Political Aides, and the Interested Public*. New York: New York Center for Research on Environmental Decisions, 2009.

Constant, N. “The Role of Citizen Science in Air Quality Monitoring.” In *Urban Pollution Science and Management*, edited by Susanne M. Charlesworth, and Colin A. Booth. Chichester: John Wiley, 2018. doi:10.1002/9781119260493.

Hess, J. J., S. Saha, and G. Luber. “Summertime Acute Heat Illness in U.S. Emergency Departments From 2006 Through 2010: Analysis of a Nationally Representative Sample.” *Environmental Health Perspectives* 122, no. 11 (2014): NLM-Export: 1209–1215.

Hurlbert, A. H., and Z. Liang. “Spatiotemporal Variation in Avian Migration Phenology: Citizen Science Reveals Effects of Climate Change.” edited by Judith Korb. *Plos One* 7, no. 2 (2012) Public Library of Science: e31662. doi:10.1371/journal.pone.0031662

Loftis, J. D., M. Mitchell, D. Schatt, D. R. Forrest, H. V. Wang, D. Mayfield, and W. A. Stiles. “Validating an Operational Flood Forecast Model Using Citizen Science in Hampton Roads, VA, USA.” *Journal of Marine Science and Engineering* 7, no. 8 (2019) Multidisciplinary Digital Publishing Institute: 242. doi:10.3390/jmse7080242

Madrigano, J., K. Ito, S. Johnson, P. L. Kinney, and T. Matte. “A Case-Only Study of Vulnerability to Heat Wave–Related Mortality in New York City (2000–2011).” *Environmental Health Perspectives* 123, no. 7 (2015): 672–678. doi:10.1289/ehp.1408178

National Academies of Sciences, Engineering, and Medicine. *Attribution of Extreme Weather Events in the Context of Climate Change*. Washington, DC: The National Academies Press, 2016.

National Academies of Sciences, Engineering, and Medicine. *Learning Through Citizen Science: Enhancing Opportunities by Design*. edited by Rajul Pandya and Kenne Ann Dibner. Washington, DC: The National Academies Press, 2018.

NOAA Climate Program Office. “Steps to Resilience.” *Steps to Resilience*. Accessed September 15. https://toolkit.climate.gov/#steps, 2019.

Pincetl, S., M. Chester, and D. Eisenman. “Urban Heat Stress Vulnerability in the US Southwest: the Role of Sociotechnical Systems.” *Sustainability* 8, no. 9 (2016): 1–13.

RK&A, Inc. “Formative Evaluation: Climate Connections Programming”, 2017.

RK&A, Inc. “Summative Evaluation: Climate Change and Resiliency”, 2018.

Shandas, V., J. Voelkel, J. Williams, and J. Hoffman. “Integrating Satellite and Ground Measurements for Predicting Locations of Extreme Urban Heat.” *Climate* 7, no. 1 (2019): 5–13. doi:10.3390/cli7010005

U.S. Environmental Protection Agency. “Heat Island Cooling Strategies.” *Epa.Gov*. Accessed September 15. https://www.epa.gov/heat-islands/heat-island-cooling-strategies, 2019.

VCU Center on Society Health. “Health Equity in Richmond, Virginia”, 2016.

Voelkel, J., V. Shandas, and B. Haggerty. “Developing High-Resolution Descriptions of Urban Heat Islands: A Public Health Imperative.” *Preventing Chronic Disease* 13, no. September (2016): 160099–6. doi:10.5888/pcd13.160099