UC Agriculture & Natural Resources
California Agriculture

Title
4-H Sustainable Polymers curriculum strengthens youth scientific literacy

Permalink
https://escholarship.org/uc/item/7h6108v5

Journal
California Agriculture, 80(1)

ISSN
0008-0845

Authors
Worker, Steven
Nayak, Roshan
Smith, Martin

Publication Date
2026-06-24

DOI
10.3733/001c.162704

Supplemental Material
https://escholarship.org/uc/item/7h6108v5#supplemental

Copyright Information
This work is made available under the terms of a Creative Commons Attribution-NonCommercial-NoDerivatives License, available at https://creativecommons.org/licenses/by-nc-nd/4.0/

Peer reviewed

eScholarship.org Powered by the California Digital Library
University of California

Worker, Steven, Roshan Nayak, and Martin Smith. 2026. "4-H Sustainable Polymers Curriculum Strengthens Youth Scientific Literacy." *California Agriculture: The Journal of UC Agriculture and Natural Resources* 80. https://doi.org/10.3733/001c.162704.

Research Article

California Agriculture: The Journal of UC Agriculture and Natural Resources

Vol. 80, 2026

4-H Sustainable Polymers curriculum strengthens youth scientific literacy

Steven Worker[1a], Roshan Nayak[2], Martin Smith[3]

[1] UC Cooperative Extension Marin, Sonoma, and Napa counties, UC Agriculture and Natural Resources,
[2] Agricultural, Leadership, and Community Education, College of Agriculture and Life Sciences, Virginia Tech,
[3] Human Ecology, College of Agricultural and Environmental Sciences, University of California, Davis

Keywords: scientific literacy, 4-H, stem education, place-based learning

https://doi.org/10.3733/001c.162704

Abstract

Plastics are integral to modern life, but their production, use, and disposal also create significant environmental and social challenges, making scientific literacy about plastics important for informed civic and personal decision making. We examined how the grade 9-12 4-H Sustainable Polymers curriculum supported youth scientific literacy in two California school settings led by 4-H educators. Using a multiple case study design, we analyzed post-program focus group data from 13 high school youth with a framework that defined scientific literacy across four dimensions: science content, scientific reasoning skills, interest and attitudes, and contribution through applied participation. Youth described learning core ideas about plastics, including material properties, life cycles, and environmental impacts. They also reported using evidence through graphs, observations, research, and discussion to interpret plastics-related issues. Hands-on, materials-based activities were described as especially engaging, and youth connected what they learned to possible actions ranging from reducing personal plastic use to supporting community, producer, and policy responses. These findings suggest that experiential, place-based environmental science education can support youth scientific literacy when learning is tied to meaningful everyday issues.

Young people need to be scientifically literate for their future careers and to participate meaningfully in civic life regarding complex environmental and public issues (Rudolph and Horibe 2015). Environmental education, a strand of science education, offers a strong context for strengthening young people's scientific literacy because it connects science learning to real-world problems and opportunities for action. Environmental education research has documented positive outcomes across knowledge, competencies, dispositions, and behavior-related domains (Ardoin et al. 2018). Effective environmental science education often uses place-based learning, an action-oriented, locally based, teaching approach shown to support both environmental science learning and civic engagement (Barnason et al. 2022; Gruenewald 2003; Sobel 2004).

The 4-H Youth Development Program is the youth program of the Cooperative Extension system. Although most California 4-H programming occurs in out-of-school-time settings, 4-H also provides enrichment programs in schools. California 4-H is based on youth development and experiential learning strategies, and science education has been a subject matter emphasis of 4-H since its inception (Worker 2012).

California 4-H is well suited for helping advance youth scientific literacy because its learn-by-doing approach emphasizes hands-on inquiry, reflection, and application. Within 4-H, scientific literacy is conceptualized broadly, encompassing science content, scientific reasoning skills, interest and attitudes, and contribution through applied participation (Smith et al. 2015). When implemented well, curriculum-based 4-H

a Corresponding author: smworker@ucanr.edu

science programming can strengthen youth scientific literacy (Smith et al. 2012; Worker et al. 2023).

Despite previous work, there is still limited understanding of how environmental science curricula developed through 4-H may strengthen scientific literacy when implemented in school settings. In this article, we present case study evidence from two California implementations led by 4-H educators in a school-adjacent public charter program and a school-based elective course. We examine how participation in the curriculum supported young people's scientific literacy regarding the production, use, and disposal of plastics.

Conceptual framing

We frame this study through two complementary perspectives: experiential learning and place-based environmental education. Experiential learning is a key pedagogy in science education. Grounded in the experiential learning cycle (Kolb 1984), youth can develop new and deeper understanding through a sequence of encountering phenomena, reflecting on observations, and applying learning in new situations. In experiential science learning, this approach is especially useful when educators make scientific goals explicit and provide a sequence of active engagement, reflection, and application of learning in new situations (Habig and Gupta 2021; Worker 2017). Authentic participation in science practices can strengthen competence and interest, particularly when youth use tools, analyze information, and engage in meaningful investigations over time (Habig and Gupta 2021). This orientation also aligns with the California 4-H vision for preparing young people to thrive in a science-driven world.

This study is also grounded in place-based learning. Environmental education has long been framed as learning in, about, and for the environment (Lucas 1972). Place-based pedagogy extends that emphasis by situating inquiry in local settings, community practices, and environmental systems, thereby increasing relevance and opening opportunities for stewardship and civic action (Barnason et al. 2022; Gruenewald 2003; Sobel 2004; Vander Ark et al. 2020). Place-based learning may be particularly powerful because it can provide youth voice, authentic participation, and opportunities to connect to community concerns (Barnason et al. 2022). Place-based education can take multiple forms; in this study, we define place primarily through the everyday settings young people experience, including home, neighborhood, school, and community, rather than through outdoor field-based investigations.

Together, these perspectives help explain why scientific literacy may be advanced when youth investigate meaningful environmental issues through hands-on inquiry, evidence-based reasoning, and reflection on possible actions.

Curriculum context and case description

Plastic pollution provided a useful context for this study because plastics are both ubiquitous in everyday life and environmentally consequential across production, use, and disposal (Shen et al. 2020). Plastics are also a complex topic well-suited for helping youth to consider material properties, product life cycles, waste systems, environmental trade-offs, and possible responses at personal, community, and policy levels. This made plastics an appropriate focal issue for a 4-H curriculum intended to strengthen scientific literacy through environmental education.

The curriculum emerged from a multi-state curriculum development effort led through the NSF Center for Sustainable Polymers, with collaborators from the University of California, the University of Minnesota, and Cornell University. Using a theory-based curriculum development strategy, the project created four age-banded content curricula (K-2, 3-5, 6-8, and 9-12) to help youth learn about plastics, evaluate environmental trade-offs, and consider how they might contribute to solutions (table 1; Smith et al. 2017).

This study focuses on the implementation of *Sustainable Polymers: Confronting the Plastic Crisis, A 4-H STEM Curriculum for Grades 9-12* (McCambridge et al. 2022), which is organized around a seven-module sequence (see online technical appendix 1). Across the modules, youth examine historical trends in plastic production and disposal; compare the properties of plastics with those of glass, paper, and metals; investigate petroleum origins and product life cycles; explore emerging bioplastics and their limitations; and research a potential solution to reduce the detrimental environmental impacts of single-use plastic and promote environmental sustainability. The curriculum uses driving questions to initiate learners' inquiry, such as why plastics became so widely used, what makes plastic versatile, and how young people might evaluate competing solutions to plastics-related environmental problems.

Although the curriculum was not designed to align fully with all Next Generation Science Standards performance expectations, each lesson identifies relevant science and engineering practices (NGSS Lead States 2013). In the context of this study, that feature is important because those practices align closely with scientific reasoning skills within our scientific literacy framework (Smith et al. 2015).

We implemented the curriculum in two school educational settings in California. One site was Sierra View (SV), a public charter science class facilitated by a county-based 4-H professional. The second was Waldorf High (WH), a high school elective course facilitated by the first author in his role as a 4-H academic advisor. SV included six ninth-grade participants and WH included seven 11th- and 12th-grade participants. Sierra View is a non-classroom-based K-12 public charter school in a rural community in the Sierra

Table 1. Four age-banded sustainable polymer content curricula

Title	Duration	Learning goals
Be a 4-H scientist! Materials in a green, clean world: 4-H polymer science curriculum for grades K-2	8 hours	Introduces young children to scientists and engineers, materials and plastics, the three Rs, and renewable versus non-renewable resources while building science process skills.
Plastics of the future for a green, clean world. A 4-H STEM curriculum for grades 3-5	10 hours	Helps youth build science and engineering skills, understand plastics and sustainability, and apply learning through service learning in home, school, or community settings.
Taking action to solve the challenge of plastics. A 4-H STEM curriculum for grades 6-8	10 hours	Engages youth in understanding plastics, sustainability, and complex systems so they can make informed decisions and contribute to their communities.
Confronting the plastic crisis: A 4-H STEM curriculum for grades 9-12	10 hours	Helps youth examine why plastics are prevalent, how material and plastic life cycles work, and how negative environmental impacts might be reduced through critical analysis, tradeoff thinking, and solution-building.

Table 2. Study sites, educators, youth, and sessions

Site	Educator	Youth	Sessions
Sierra View (SV) public charter school science class	4-H professional, cross-cultural education (MS) and organizational leadership (EdD)	Six ninth graders	Six 90-minute sessions
Waldorf High (WH) school elective class	4-H academic advisor, community development (MS) and education (PhD)	Seven 11th and 12th graders	Seven 85-minute sessions

Nevada, California, that primarily serves homeschool families. Waldorf High is a small private K-12 school in a Northern California town using a Waldorf pedagogy. Both 4-H facilitators were trained in the curriculum's goals and content and had substantial experience in science pedagogy. In this article, we treat these sites as two illustrative cases of curriculum implementation in school settings (table 2).

Methods

This study used a multiple case study design to examine how participation in the grade 9-12 Sustainable Polymers curriculum supported youth scientific literacy across two illustrative cases. The two implementation sites, differing learning contexts, grade levels, and educators, were treated as complementary cases rather than as directly comparable conditions. We defined scientific literacy using the framework developed by Smith et al. (2015), which includes four dimensions: science content, scientific reasoning skills, interest and attitudes, and contribution through applied participation. This framework guided both data collection and analysis.

Data collection

We conducted post-program focus group interviews with participants using eight prompt stems designed to elicit what youth learned about plastics and environmental impacts, how they reasoned with evidence and activities from the curriculum, what they found engaging, and how they viewed possible actions (see online technical appendix 2). Focus groups lasted 22 to 30 minutes, were audio-recorded, and were transcribed for analysis.

Data analysis

The first author analyzed transcripts using deductive thematic analysis (Braun and Clarke 2022). Transcripts were coded at the sentence level using the four dimensions of scientific literacy, and more than one code could be applied to the same sentence when appropriate. Content codes captured references to plastics, petroleum, biodegradability, life cycle, material properties, waste pathways, and emissions (number of code applications: SV = 34, WH = 17). Scientific reasoning codes captured references to experimentation, testing, graphs, data, research, observation, and simulation (SV = 16, WH = 9). Interest and attitudes codes captured expressions such as fun, favorite, interesting, en-

joyed, liked, cool, or new (SV = 20, WH = 29). Contribution through applied participation codes captured references to reducing, reusing, recycling, volunteering, community cleanup, policy, producer and consumer responsibility, sharing what was learned, or investing in solutions (SV = 12, WH = 2). An additional code, youth perspectives on the learning experience, was used when participants commented on pedagogy, facilitation, curriculum activities, or other aspects of the learning environment (SV = 5, WH = 18).

After initial coding, excerpts were compiled within each code and reviewed first within each study site and then across sites to identify recurring patterns, convergences, and divergences. This analytic process allowed us to examine not only what youth said they learned, but also how they described reasoning about plastics, engaging with the curriculum, and envisioning possible responses to plastics-related environmental issues.

Findings

At both sites, SV and WH, participants described learning that reflected all four dimensions of scientific literacy used in this study. Participants described learning about plastics and polymers, interpreting data and evidence about environmental impacts, identifying activities that made the curriculum engaging, and proposing possible actions to address plastics-related problems. Although the implementation sites differed in learning context, grade level, and educator, similar patterns were evident among youth responses in both cases. In the sections that follow, we present findings by the four dimensions of scientific literacy and then report on youths' perspectives on their learning experience.

Science content

Youth at both sites described learning core ideas about plastics, including material properties, environmental impacts, and life-cycle trade-offs. They also moved beyond seeing plastic as a familiar everyday material toward understanding it as a complex environmental issue, although SV youth emphasized environmental hazards and quantitative comparisons, whereas WH youth more often framed plastics through utility and life-cycle reasoning.

- A SV young person's explanation of microplastics showed sophisticated detail: "Plastic can't break down completely into a biological material, so it just remains as tiny, tiny, tiny little bits of plastic that you can't see with the naked eye, but they're everywhere." Youth compared materials, noting aluminum's "higher melting point" makes it preferable for cooking surfaces. Several mentioned U.S. Environmental Protection Agency waste disposal graphs and articulated "we learned about the discrepancies between the disposal amounts and the amount produced" but were also struck by "how versatile plastic is and how much it affects the way we live."
- WH youth likewise cited specific takeaways but framed them in a broader life-cycle perspective. Youth said their participation in the curriculum made them "question the way I view plastics, which was really interesting because it really turned my perception around" after "I learned a lot about the history and looking at the graphs and different sheets of information that were brought each day" for youth to compare plastic to aluminum, glass, and paper data. Others reflected a changing perception about plastic being a great material but also problematic, for example: "now I understand that plastic . . . has so many good ways of using it; it's just the problems that we are . . . looking at [are challenging]."

Scientific reasoning skills

Youth at both sites described using scientific reasoning as they interpreted graphs, evaluated information sources, and connected evidence to conclusions about plastics. In comparing sites, SV youth emphasized data quality and source credibility, whereas WH youth more often described observation-based reasoning and the use of personal or household data to make sense of plastics in everyday life.

- SV learners articulated source criteria, preferring ".gov or .edu" websites because ".gov or .edu tend to be more reliable because they're government and education websites, instead of .com or .org, which can be for private profit or just privately owned."
- A WH youth described making sense of the topic through graphing data and documenting household use, explaining that understanding "the role plastic plays in our lives" was "a big part of this class."

Interest and attitudes toward science

Youth in both groups reported the greatest engagement during hands-on, materials-based activities. Across both sites, these comments suggest that interest was strongest when learning involved making, testing, and discussion; however, WH youth more often reflected on pedagogy and pacing while SV youth frequently named specific activities they enjoyed.

- SV enthusiasm coalesced around the HydroPod lab: "I'd say the hydro pods." Another youth expressed enjoyment with presenting a case, "it was kind of fun making the presentation."
- WH youth echoed this enthusiasm, with several naming "making the bio-plastics [hydropods]" as a favorite activity. They also described the curriculum as interactive and materials based, suggesting that hands-on learning increased their interest.

Contribution through applied participation

Youth at both sites connected what they learned to possible action, indicating that the curriculum supported thinking beyond the learning setting. Across sites, SV youth more often proposed immediate consumer and community actions, whereas WH youth more often named systems-level responses such as producer accountability, policy change, and public education.

- SV youth proposed immediate, local actions: reuse utensils, "clean up trash and volunteer for Earth Day, or river cleanup to help keep the environment clean" and "hold [producers] accountable for the waste that they're creating. Not just the people buying it [consumers]."
- WH learners coupled personal behavior with systemic change. One youth envisioned work "on a policy level. Big company level," while another stressed peer education and continuous awareness of plastics in daily life.

Youth perspectives on the learning experience

Youth at both sites described the curriculum as most effective when it combined hands-on investigation with collaborative discussion. Across sites, participants also identified areas for improvement, particularly reducing text-heavy segments, adjusting pacing, and providing stronger supports for consolidating complex ideas.

- SV youth consistently asked for more inquiry time and fewer worksheets, asking for more time to build, test, and present. One youth offered, "Maybe more hands-on parts of the curriculum, because a lot of it was reading and creating graphs, and I think it would help to retain information if there's more experimentation." They also proposed concrete investigation formats that fit the curriculum's goals: "We could do a small-scale simulation of how plastic gets into the ocean or something."
- WH youth praised the interactive, materials-based design while calling for deeper explanatory support and pacing adjustments. One youth shared a comment about the length of sessions, "I think it was a little hard. This class is an hour and a half or something, it's a little hard." Several asked for more direct instruction to consolidate ideas: "Maybe one day there could be a 30-minute lecture so we could either take notes or just have something absorbed into us about more information," and paired with youth informational handouts, "I could have handled a lot more information. I think some nice supplementary videos too." At the same time, they affirmed the experiential pedagogy, saying "It was very interactive and very material-based, which is really interesting," and saw the approach as promising for future courses: "It's exciting that this kind of seems like a new model of class that could be taught."

Discussion

This study examined how high school-aged youth in two California school implementations led by 4-H educators described their learning after participating in the grade 9-12 Sustainable Polymers curriculum. Overall, the findings indicate that the curriculum supported scientific literacy across the four dimensions used in this study: science content, scientific reasoning skills, interest and attitudes, and contribution through applied participation. Youth described plastics as materials with useful properties, environmental consequences, and multiple possible responses. A recurring theme was heightened awareness of the ubiquity of plastics. In this sense, the findings suggest an emergent form of plastic literacy in which youth connected disciplinary ideas about polymers with reasoning about production, use, disposal, and action.

Experiential, place-based science learning

Experiential and place-based pedagogies can provide socially supported, inquiry-oriented learning that engages youth in active learning. Youth described learning through graph interpretation, observation of materials, collaborative discussion, and connections between plastics and everyday life. At SV, youth discussed data quality, duplicated values, and source credibility. At WH, youth described using graphs and household inventories to make sense of plastics in their own lives. These examples show how experiential, environmental science education can support scientific literacy when youth interpret evidence, explain trade-offs, and discuss what the concepts mean.

Additionally, our findings support the value of experiential learning in environmental science education. Youth feedback suggests that the experiential learning sequence was especially effective when activities centered on handling materials, testing ideas, and discussing results. At the same time, the findings suggest that experiential learning alone is not sufficient. Youth at both sites also identified areas where learning could be strengthened, including clearer framing, pacing adjustments, and more opportunities to consolidate complex ideas. This supports prior 4-H research showing that facilitator decisions play an important role in shaping whether hands-on activities become meaningful learning opportunities (Worker 2017).

Furthermore, these findings clarify how place-based environmental education can be viewed from an alternative perspective. Environmental education has long been framed as learning in, about, and for the environment (Lucas 1972), while place-based approaches are often valued for increasing relevance, engagement, and opportunities for stewardship and civic

action (Gruenewald 2003; Sobel 2004; Vander Ark et al. 2020). In these two cases, place-based learning was visible less through outdoor field investigation than through youths' efforts to understand plastics through the systems closest to them: household consumption, school and community waste practices, clean-up efforts, producer responsibility, and policy decisions. Place became meaningful when the curriculum helped youth connect polymer science to the infrastructures and choices that shape everyday material life. This pattern is consistent with research showing that environmental education can support knowledge, competencies, dispositions, and behavior-related outcomes (Ardoin et al. 2018), and that participatory environmental action may contribute to civic engagement and positive youth development (Barnason et al. 2022).

Cross-case interpretation

Differences between the two sites should be interpreted cautiously, but they still offer useful insights into how the same curriculum functioned across distinct contexts. SV youth (younger) more often emphasized environmental hazards, quantitative discrepancies, and immediate local action such as reducing waste and participating in cleanups. WH youth (older) more often framed plastics through life-cycle reasoning, systems-level responsibility, and policy or producer change. These differences indicate that the curriculum supported multiple entry points into scientific literacy while maintaining a common focus on evidence, trade-offs, and action. They also reinforce the importance of avoiding one-size-fits-all assumptions about how adolescents engage with environmental science.

Implications for Cooperative Extension

These findings point to several practical design considerations. Youth engagement appeared strongest when activities moved beyond information delivery toward investigation, discussion, and interpretation. Youth also benefited from opportunities to use evidence in multiple forms, including graphs, materials testing, inventories, and collaborative sense-making. In this context, place-based environmental education may be strengthened by making local systems more visible, including school waste practices, household consumption, local cleanup efforts, and community or policy responses. Finally, the curriculum appears especially promising when it gives youth structured opportunities to identify, justify, and communicate possible responses to an authentic environmental problem. This matters because it reflects how youth in this study described learning, engagement, and possible action.

Limitations

The study is based on two cases and relies on post-program focus group data. Accordingly, the findings should be interpreted as evidence of how youth described their learning after participation rather than as change over time. Data analysis was conducted by one researcher, thereby introducing potential bias. The study also did not include forms of triangulation that would support stronger claims about how facilitation shaped outcomes. In addition, because the two sites differed in learning context, grade level, and educator, differences between cases cannot be attributed to any single factor. Future research could examine how youth outcomes vary across facilitation approaches or learning settings, and could test whether stronger explanatory framing or more explicit local action components influence scientific literacy.

Conclusion

This study illustrates how a 4-H-developed curriculum on plastics designed for grades 9-12 supported youth scientific literacy in two California school settings. Youth described learning core ideas about plastics and polymers, reasoning with evidence about environmental impacts, engaging most strongly with hands-on activities, and envisioning actions that ranged from personal behavior change to broader community and policy responses. These findings suggest that environmental science curricula can do more than build awareness of a topic. When grounded in experiential learning and connected to issues that youth recognize in everyday life, such curricula may support scientific literacy as knowledge, reasoning, engagement, and participation.

For 4-H, these findings underscore the value of environmental education that is interactive, evidence-rich, and locally meaningful. Plastics proved to be a productive context because the topic linked chemistry and materials science with waste systems, environmental trade-offs, and possible action. More broadly, this study suggests that environmental education can support scientific literacy when youth are invited to investigate, interpret, discuss, and imagine how science relates to the places and systems around them.

Acknowledgments

We thank Cheryl L. Meehan, Emily K. Manroe, Jennifer McCambridge, Anne Stevenson, Alexa Maille, Amie Mondl, and Charles Malone for their contributions to curriculum development. We acknowledge and appreciate Kelsi Williams-Karschner for field implementation. This work resulted from a partnership between the NSF Center for Sustainable Polymers, University of Minnesota Extension, University of California Agriculture and Natural Resources, and Cornell University Cooperative Extension. This work was supported by the NSF Center for Sustainable Polymers, an NSF Center for Chemical Innovation (CHE-1901635).

Submitted: August 13, 2025 PDT. Accepted: May 07, 2026 PDT.

This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CCBY-NC-ND-4.0). View this license's legal deed at https://creativecommons.org/licenses/by-nc-nd/4.0 and legal code at https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode for more information.

References

Ardoin, N. M., A. W. Bowers, N. W. Roth, and N. Holthuis. 2018. "Environmental Education and K-12 Student Outcomes: A Review and Analysis of Research." *J Environ Educ* 49 (1): 1–17. https://doi.org/10.1080/00958964.2017.1366155.

Barnason, S., C. J. Li, D. M. Hall, et al. 2022. "Environmental Action Programs Using Positive Youth Development May Increase Civic Engagement." *Sustainability* 14 (11): 6781. https://doi.org/10.3390/su14116781.

Braun, V., and V. Clarke. 2022. *Thematic Analysis: A Practical Guide*. Sage Publications Ltd.

Gruenewald, D. A. 2003. "The Best of Both Worlds: A Critical Pedagogy of Place." *Educ Res* 32 (4): 3–12. https://doi.org/10.3102/0013189X032004003.

Habig, B., and P. Gupta. 2021. "Authentic STEM Research, Practices of Science, and Interest Development in an Informal Science Education Program." *Int J STEM Educ* 8: 57. https://doi.org/10.1186/s40594-021-00314-y.

Kolb, D. A. 1984. *Experiential Learning: Experience as the Source of Learning and Development*. Prentice-Hall.

Lucas, A. M. 1972. "Environment and Environmental Education: Conceptual Issues and Curriculum Implications." Doctoral dissertation, Ohio State University. OhioLINK Electronic Theses and Dissertations Center. http://rave.ohiolink.edu/etdc/view?acc_num=osu1298993758.

McCambridge, J., E. K. Manroe, C. Meehan, et al. 2022. *Sustainable Polymers: Confronting the Plastic Crisis. A 4-H STEM Curriculum for Grades 9–12*. NSF Center for Sustainable Polymers. University of Minnesota.

NGSS Lead States. 2013. *Next Generation Science Standards: For States, by States*. National Academies Press.

Rudolph, J. L., and S. Horibe. 2015. "What Do We Mean by Science Education for Civic Engagement?" *J Res Sci Teach* 53 (6): 805–20. https://doi.org/10.1002/tea.21303.

Shen, M., W. Huang, M. Chen, et al. 2020. "(Micro)Plastic Crisis: Un-Ignorable Contribution to Global Greenhouse-Gas Emissions and Climate Change." *J Clean Prod* 254: 120138. https://doi.org/10.1016/j.jclepro.2020.120138.

Smith, M. H., S. M. Worker, A. P. Ambrose, and L. Schmitt-McQuitty. 2015. "Scientific Literacy: California 4-H Defines It from Citizens' Perspectives." *Calif Agr* 69 (2): 92–97. https://doi.org/10.3733/ca.v069n02p92.

Smith, M. H., S. M. Worker, C. L. Meehan, et al. 2017. "Defining and Developing Curricula in the Context of Cooperative Extension." *J Ext* 55 (2): 22. https://doi.org/10.34068/joe.55.02.22.

Smith, M., K. Heck, and S. Worker. 2012. "4-H Boosts Youth Scientific Literacy with ANR Water Education Curriculum." *Calif Agr* 66 (4): 158–63. https://doi.org/10.3733/ca.v066n04p158.

Sobel, D. 2004. *Place-Based Education: Connecting Classrooms and Communities*. The Orion Society.

Vander Ark, T. V., E. Liebtag, and N. McClennen. 2020. *The Power of Place: Authentic Learning through Place-Based Education*. ASCD (Association for Supervision and Curriculum Development).

Worker, S. M. 2012. *History of Science Education in the 4-H Youth Development Program*. Monograph. University of California, Agriculture and Natural Resources. https://4-hhistorypreservation.com/eMedia/Reports/CA4H_135384.pdf.

Worker, S. M. 2017. "Volunteer Educators Bring Their Own Ideas about Effective Teaching to a 4-H Curriculum." *Calif Agr* 71 (4): 208–13. https://doi.org/10.3733/ca.2017a0021.

Worker, S. M., S. Neas, D. Espinoza, et al. 2023. "Youth Science Learning as/for Community Participation: Examples from Youth Participatory Action Research." *J Youth Dev* 18 (1). https://doi.org/10.34068/JYD.18.01.03.

Supplementary Materials

Technical appendices

Download: https://californiaagriculture.org/article/162704-4-h-sustainable-polymers-curriculum-strengthens-youth-scientific-literacy/attachment/347406.docx?auth_token=J_Y8G1mU6k4Rxd5c1YZI