The Potential of “Civic Science Education”: Theory, Research, Practice, and Uncertainties

Brett Levy  
*University at Albany, State University of New York*, bllevy@albany.edu

Alandeon Oliveira  
*University at Albany, State University of New York*, aoliveira@albany.edu

Cornelia Harris  
*University at Albany, State University of New York*, charris2@albany.edu

The University at Albany community has made this article openly available. Please share how this access benefits you.

Follow this and additional works at: https://scholarsarchive.library.albany.edu/etap_fac_scholar

Part of the Education Commons

**Recommended Citation**  
Levy, Brett; Oliveira, Alandeon; and Harris, Cornelia, "The Potential of “Civic Science Education”: Theory, Research, Practice, and Uncertainties" (2021). *Educational Theory and Practice Faculty Scholarship*. 35. https://scholarsarchive.library.albany.edu/etap_fac_scholar/35

This work is licensed under a Creative Commons Attribution 4.0 International License. This Article is brought to you for free and open access by the Educational Theory and Practice at Scholars Archive. It has been accepted for inclusion in Educational Theory and Practice Faculty Scholarship by an authorized administrator of Scholars Archive.

Please see Terms of Use. For more information, please contact scholarsarchive@albany.edu.
The Potential of “Civic Science Education”: Theory, Research, Practice, and Uncertainties

Brett L. M. Levy
University at Albany, State University of New York
bllevy@albany.edu

Alandeon W. Oliveira
University at Albany, State University of New York
aoliveira@albany.edu

Cornelia B. Harris
University at Albany, State University of New York
charris2@albany.ed

Citation Information for Published Version:
Levy, B. L. M., Oliveira, A. W., & Harris, C. B. (2021). The potential of “civic science education”: Theory, research, practice, and uncertainties. Science Education, 1-23. DOI: 10.1002/sce.21678

Acknowledgments:
We would like to thank John Rudolph, Noah Weeth Feinstein, Jane, Lo, and Jay Shuttleworth for providing feedback and encouragement as we developed the ideas presented in this manuscript. We also appreciate the assistance of Lauren Collet-Gildard and Hyejin Park, who identified some of the prior research explored in this paper.
Abstract
This paper explores the potential of civic science education (CSE), which includes experiences that have been intentionally designed to foster or enhance individuals’ interactions with and/or engagement in science-related public matters. To begin, we provide a theoretically-grounded definition of CSE, including three sub-categories: foundational, exploratory, and purposefully active. We then explore the scholarly arguments for why enacting CSE could help to support students’ science learning and civic engagement and also strengthen civil society. Next, the paper examines current educational practices related to CSE, such as citizen science, exploring socioscientific issues, and various civic education pedagogies, detailing what researchers have learned from empirical studies of these practices. Building on this prior theory and research, we argue that CSE could motivate students both to learn science and become engaged in civic issues, with slightly different expected outcomes across the three CSE categories. We conclude by encouraging educators and researchers to explore the great potential of such practices, providing specific recommendations for curriculum development and empirical studies.

Keywords
socioscientific issues • citizen science • civic engagement • motivation • civic science
1 | Introduction

As people around the world grapple with major public health and environmental challenges, scientists and leaders have become increasingly concerned about our society's capacity to address these challenges effectively (e.g., Ferreira et al., 2018; Somerville, 2020). For many years, scholars have been interested in how education might contribute to enhancing public policy and decision-making related to science (e.g., Bazzul, 2015; Bencze & Carter, 2011; Feinstein & Kirchgasler, 2015; Rudolph & Horibe, 2016), and in the midst of COVID-19, climate change, and other disturbing trends, these matters have taken on a renewed urgency.

Given our current context, this paper aims to highlight the importance and potential of civic science education (CSE), that is, educational experiences that support individuals' ability to understand, explore, and take informed action on public issues related to science. We contend that expanding such opportunities could strengthen students' learning of important scientific content and engagement in science-related public matters, ultimately improving the management of these public issues and civil society overall. In this paper, we explore theory, research, practice, and uncertainties related to CSE, and we also call for more research in domains that could further enhance the enactment of CSE.

In the United States, the Next Generation Science Standards (NGSS Lead States, 2013) acknowledge the role of science education in supporting informed civic participation. For example, the standards state that students should “design, evaluate, and refine a solution for reducing the impact of human activities on the environment and biodiversity” (HS-LS2-7). The document mentions the word “citizen” eleven times, noting the importance of “civic decision making” (p. 7), becoming a “critical consumer of science” (p. 71), and learning about science-related issues that “affect their lives and communities” (p. 286).
Similar trends can be found in the national education policies of other countries as well. For example, in Brazil's National Curriculum Parameters (PCN, 2018), which contain the content learning standards for elementary and secondary schools nationally, it is emphasized that, together with discipline-specific learning, schooling should involve student preparation for the exercise of citizenship in a democratic context and development of a fuller awareness of their responsibilities and rights. Civic participation is most strongly emphasized in biology, noting that, “In the teaching of Biology, it is essential to develop...citizens who are able to carry out practical actions, form judgements and make decisions” (p. 45).

Despite the important stated goals of educational standards documents in the United States and beyond, we argue that students must also be prepared to take a more active role in addressing science-related public issues (e.g., Bazzul, 2015) and that such an active role could enhance students' learning in science (e.g., Bencze & Carter, 2011). Scholars in other sub-fields of education, such as social studies and environmental education, have long recognized the importance of preparing youth for civic action, and their standards reflect this stance.¹ We ask that you, our readers, consider the extent to which science education, through NGSS, research, teaching, and other avenues, may join these fields in making informed, active democratic participation a high priority.

2 | What is CSE?

For several decades, scholars of the natural and social sciences have argued that science education should equip students to collaboratively build a better society, not only by enabling

¹ National Council for the Social Studies (2013). College, career, and civic life (C3) Framework for social studies state standards. Standards D4.8.6-8 and D4.8.9-12, p. 62; North American Association for Environmental Education. Guidelines for excellence, K-12 learning. Strands 3 and 4, pp. 43–48, 63–70.
people to make sense of their world but also by preparing them to participate in science-related deliberations that shape society (Clark & Illman, 2001; Garlick & Levine, 2018; Rutherford & Ahlgren, 1989). Numerous sub-fields and federally-funded grant programs have emerged to explore students' learning in this domain, including science, technology, and society (STS) programs (e.g., Bennett et al., 2007), socioscientific issues (SSI) curricula (e.g., Zeidler et al., 2005), and citizen science, among others (see Table 1). Likewise, scholars and researchers of

Table 1 | Sub-Fields of Education Related to CSE

| Sub-Field | Brief Definition |
|-----------|-----------------|
| Socio-Scientific Issues (SSI) | Science instruction should focus on scientific issues with social ramifications. Science is learned through scientific argumentation (evidence-based), moral reasoning, and ethical deliberation as students seek to collaboratively solve cases or dilemmas (authentic, real-world problems) (Zeidler, 2003). |
| Science, Technology, & Society (STS) | The STS movement emphasizes the need for science to be taught in relation to other spheres of life (rather an isolated subject). With a focus on interconnections to other human endeavors like technology and society, science is taught in the context of recent technological advancements in the students’ social world (Solomon & Aikenhead, 1994). |
| Science, Technology, Societies & Environments (STSE) | “STSE education prioritizes understanding relationships, [and] it also is important to have realistic conceptions of each element - including about the nature of science and technology (NoST), the nature of societies (e.g., sociology) and the nature of environments” (Bencze, 2019). |
| Citizen Science (aka Public Participation in Science Research) | “[T]he public participates voluntarily in the scientific process, addressing real-world problems in ways that may include formulating research questions, conducting scientific experiments, collecting and analyzing data, interpreting results, making new discoveries, developing technologies and applications, and solving complex problems” (United States General Services Administration, 2020). |
| Environmental Education (EE) | “Environmental education is aimed at producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution” (Stapp, 1969, p. 34). |
| Education for Sustainable Development (ESD) | “[E]mpowers learners to take informed decisions and responsible actions for environmental integrity, economic viability and a just society, for present and future generations, while respecting cultural diversity” (UNESCO, 2021). |
| Civic Science | “[A] discipline that considers science practice and knowledge as resources for civic engagement, democratic action, and political change” (Garlick & Levine, 2018, p. 692). |
environmental education have examined how students can develop an understanding of our natural world and adopt the values and skills needed to care for it (e.g., Huckle, 2009; Stapp, 1969; UNESCO, 1978, 2012); and the field of social studies education has developed strategies, standards, and research to support the development of informed civic participation on science-related and other public matters (e.g., Levstik & Tyson, 2008; Sherrod et al., 2010).

In this paper, we link these sub-fields together under the umbrella term CSE, with the hope that we can establish a common purpose that enables us to strengthen this important area of science education. As the label implies, CSE sits at the intersection of three areas—civic life, science, and education (see Figure 1). By civic life, we refer to interactions with and/or engagement in public matters, which “include the commons, the distribution of private goods, and decisions about what actions to prohibit or promote” (Levine, 2007, p. 7). In contrast to

![Figure 1](image)

**Figure 1**  |  Civic science education at the intersection of three areas
personal issues, public matters are of concern to numerous people, perhaps entire communities, states, nations, or global regions. The precise line between public and private matters is not always clear (e.g., certain purchasing decisions), but certainly issues related to our natural environment and public health reside in the public sphere.

Like the term civic life, science and education have numerous definitions, but we conceptualize them broadly. As Wilson (1999) notes, science includes not only knowledge concerned with the physical world and its phenomena but also the systemic method of building and organizing knowledge via testable explanations and predictions. This perspective is integrated into the NGSS, and recent research in science education has echoed these standards' emphasis on both content and method (Morales-Doylev et al., 2019). But beyond this, we support Rudolph's (2014) notion that science, and science education, can include inquiry into social processes and society more broadly.

Meanwhile, we conceptualize education as the process of facilitating the development of knowledge, skills, values, beliefs, or habits. These processes can occur in a school or in a variety of other, less formal settings, such as a community program or informal association. Whereas classrooms can be excellent sites of learning, youth also spend substantial time in out-of-school programs where they can have hands-on learning experiences, such as analyzing watersheds through exploring a local creek system (Fitanides, 2020). While we agree that learning occurs throughout our broad life experiences (e.g., Lave & Wenger, 1991), we conceptualize education as experiences that have been deliberately structured to support learning. Thus, CSE includes experiences that have been intentionally designed to foster or enhance individuals' interactions with and/or engagement in science-related public matters. CSE experiences may vary widely in the extent to which civic issues are included, but in our view, an educational experience can be
classified as CSE if engagement with science-related public matters are part of the framing and among the major objectives of a particular experience.

Civic education, a core aspect of CSE, aims to foster what Torney-Purta et al. (2015) call civic learning. They contend that civic learning includes two main dimensions: (1) civic engagement, which involves civic motivations, values, and activities and (2) civic competency, which includes civic knowledge, analytical skills, and participatory skills. Thus, civic learning does not necessarily mean engaging students in formal political activities; rather, it includes a much broader set of experiences, both formal and informal, individual and collective. For example, whereas learning for civic engagement includes experiences that support students' interest in following the news and participating in discussions of current events, learning for civic competence includes, among other things, experiences that support young people's understanding of public issues and their ability to thoughtfully analyze those issues. Many public issues, such as climate change and COVID-19, involve scientific questions and processes that need to be broadly addressed, so we believe that civic learning about science-related issues (along both dimensions) is vital for enhancing informed democratic participation.

Drawing on prior scholarship and research in political science, civic education, environmental studies, and science education (explored more in the following sections), we identify three categories of CSE: foundational, exploratory, and purposefully active (see Table 2). Whereas foundational CSE emphasizes the development of essential knowledge, skills, and values, exploratory CSE involves the collection and analysis of data on science-related civic issues. Meanwhile, purposefully active CSE prioritizes engagement in the public sphere by, for example, raising awareness about or designing and enacting plans to affect a specific science-related public issue.
Table 2 | Categories of Civic Science Education

| CSE Category     | Definition                                                                                                                                 |
|------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| Foundational     | CSE experiences that involve exposure to, discussion of, and/or peer interactions around science-related public matters, with a focus on the development of related knowledge, skills, and values |
| Exploratory      | CSE experiences that involve asking questions and collecting and/or analyzing data and/or evidence related to science-related public matters    |
| Purposefully Active | CSE experiences that involve raising awareness, advocating, organizing others, designing solutions, and/or purposefully participating in efforts to address science-related public matters |

Note. CSE experiences may vary widely in the extent to which civic or scientific issues are included.

Thus, CSE may or may not emphasize active participation, and we recognize the numerous forms that civic engagement can take (Checkoway & Aldana, 2013). Foregrounding the civic nature of scientific issues can help students develop a public standpoint and view scientific matters from a broader societal perspective (Árnason, 2012), but some CSE practitioners may prefer not to emphasize active participation—instead supporting their students' engagement as monitorial citizens (Schudson, 1999), occasional citizens (Leydet, 2006), or personally responsible citizens (Westheimer & Kahne, 2004). Some may prepare their students for latent rather than manifest forms of sociopolitical involvement (Ekman & Amnå, 2012), supporting their students' development of key skills, such as writing about socioscientific issues, that they can leverage when the need arises. Hence, CSE can involve fostering students' willingness and capacity to share accurate information, advocate, and help organize others when there are vital science-related public issues at stake.

Authentic civic engagement is typically characterized by active participation (Llewellyn et al., 2010), but such participation can include deliberation, discussion, ongoing learning, and developing community relationships, in addition efforts to influence actual policies (Checkoway & Aldana, 2013; Levine, 2013). Through CSE, students can learn important scientific concepts...
while also developing pro-civic attitudes and skills, and educators can make room for the pursuit of evidence-based understandings that can inform collective action in the public sphere (Roth & Lee, 2002). Such action can include traditional forms of participation, such as starting petitions, attending city council meetings, and participating in letter-writing campaigns, but they also include less direct engagement, such as participating in online forums, posting information on social media, volunteering on a large or small scale, donating or raising money for a science-related civic cause, or even simply staying informed about such issues (Bishop & Low, 2004; Pattie & Seyd, 2003).

While CSE aims to foster engagement with the public sphere, it is important to recognize how broad public contexts have shaped education itself and influenced our own perspectives and paradigms (see Figure 2). As Bronfenbrenner's (1979) ecological systems theory and Latour's...
(2005) actor network theory explain, we and our communities exist within a complex larger context, with numerous proximal and distal forces that constantly influence each other. Not only are our lives affected by the shifting climate and biomes, but we also operate within a set of (also shifting) institutional contexts and cultural values, which prioritize some matters over others, privilege certain modes of expression and interaction, and grant more credence and power to individuals with particular characteristics.

Furthermore, as Foucault (1972) noted, we must also consider how power flows through social networks. Whereas all actors can express power, the mechanisms of power tend to reside in certain authoritative institutions and individuals. And although science is widely regarded as systematically uncovering objective truth, it can be and has been used by authorities to perpetuate social injustices (Gregory & Miller, 1998).

Indeed, science is regularly co-opted by politicians across the political spectrum and has been described as the “discourse of the late capitalist state” (Aronowitz, 1988). Thus, rather than learning to view science as the dominant mode of epistemic legitimation and the source of apolitical/ahistorical truths, students should be encouraged to critically explore links between scientific ideas and social structures. Such critical examination can support students' development of emancipatory forms of knowledge, which question civic power dynamics and have the potential to emancipate people from institutional forces that limit their participation in democratic life (Habermas, 1971). Indeed, examining and critiquing current power structures and “blurring the lines” between scientists and the public could serve to strengthen deliberation about how best to address science-related public challenges (Warmbrod et al., 2019). Such contextual and critical perspectives can shape the content, skills, and values of CSE, whether the curricular focus is foundational, exploratory, or purposefully active.
Unfortunately, some major trends in science education assume a technocratic view of science, largely neglecting some of these larger contextual matters. The Next Generation Science Standards have numerous positive attributes, but they make little mention of the harmful aspects of science, such as chemical contamination (Morales-Doyle et al., 2019) or the sociopolitical forces that may incentivize such harm. Nonetheless, it is possible to engage in the content of NGSS through a sociopolitical or even a social justice lens, examining how, for example, chemical contaminants have affected water supplies in Flint and elsewhere.

Moreover, Rudolph (2020) advocates for a renewal of “the moral purpose of science education” not only for the improvement of society but also as a way of mitigating public skepticism of science and distrust of scientists. He argues that students should come to view science as a source of reliable knowledge (as opposed to absolute truth) that can help them make ethical decisions and do “what's right.” Rudolph contends that helping students develop these perspectives requires a shift in the focus of science instruction from isolated individual practices to social and institutional practices (collaborative, society-oriented processes) that operate within our democratic system. We agree that exploring these ethical dimensions would be beneficial, enabling students to consider the broader contexts and values in which science operates and preparing them for responsible decision-making and civic participation.

CSE practices could help pave the way for such learning. Whether educators pursue foundational, exploratory, or purposefully active CSE, students can begin to realize how scientific knowledge and methods influence and are influenced by broad social, institutional, and ecological contexts—and thus start to see themselves as inexorable participants in a broader collective process. Such a realization inevitably raises questions about how to be an ethical
decision-maker and what values we should prioritize, and practitioners of CSE should be prepared to explore these challenging yet crucial issues.

3 | Why CSE Matters

3.1 Students’ limited motivation in civic and science education

We believe that CSE has the potential to address important practical problems. Unfortunately, students in the United States and beyond have demonstrated limited motivation to learn science or engage actively in civic issues. Researchers have long found that most US students have little scientific knowledge, especially compared to students in other industrialized countries (Desilver, 2017). On nationally administered exams in 2015, only about 22 percent of US twelfth graders and 34 percent of US eighth graders performed at the “proficient” level or better in science (NAEP, 2015). Performance among fourth graders was only slightly better, with about 38% proficient or better. Scholars suggest that some of this low performance in science is related to students' limited motivation to learn science (Osborne et al., 2003), a trend that can depress not only academic achievement but also lifelong learning.

When individuals have more positive attitudes towards science, they tend to perform better in related coursework (OECD, 2007; Schiefele et al., 1992) and pursue science learning beyond the classroom (Osborne et al., 2003). Students' interest in science varies by sex (Haussler & Hoffman, 2000) and self-concept (Reis & Park, 2001), but regardless of these factors, interest in these school subjects tends to decrease as individuals progress from elementary to middle school and even further when they reach high school (Osborne et al., 2003). Although teens tend to be interested in science in general, they express negative attitudes towards their science
coursework (Amgen Foundation, 2016) and often view it as irrelevant to their lived experiences (Jenkins, 2011).

At the same time, many youth are not very engaged in civic issues. Despite required coursework in civics or government in most states, political participation among youth in the United States has remained low, with about half of 18- to 29-year-old casting ballots in 2008 (Kirby & Kawashima-Ginsberg, 2009) and 2012 (Carpenter, 2012) and well below half in 2016 (Center for Information and Research on Civic Learning and Engagement, 2020a). Even in the voter surge of 2020, just 50% of eligible youth cast ballots (Center for Information and Research on Civic Learning & Engagement, 2020b). On voter turnout overall, the US ranked 28th among 35 highly developed democratic states belonging to the Organization for Economic Cooperation and Development (Pew Research Center, 2017), and most millennials feel that they have no voice in political processes (Center for Information and Research on Civic Learning and Engagement, 2016).

Educators, scholars, and policymakers have grown concerned about these trends in civic engagement and science education. Kyle (1996) and Bencze and Carter (2011) call for a school science curriculum that fosters political literacy and engagement, and produces scientifically and politically literate activists rather than apolitical and passive critics. Likewise, Hodson (2003) argues that students need to be civically engaged by having the opportunity to actively confront real societal problems (e.g., racism, sexism, classism, injustice) and fight for what is right, good, and just. And Onwu (2017), focusing on the South African context, calls for a socially responsible science education that is embedded in socioscientific issues. These practices and purposes are central to the concept of CSE, and we argue that they could not only enhance civic life but could also contribute to meaningful scientific learning.
3.2 Enhancing scientific learning

Furthermore, CSE—which can help relate science content to students’ own lives—can have a positive impact on students’ scientific learning. Prior research indicates that when students are intrinsically motivated to learn content, they demonstrate greater interest, persistence, and learning (Renninger & Hidi, 2016; Schiefele, 2009). Educators can build students’ intrinsic motivation in various domains by enhancing the four following elements related to the target task or subject: competence beliefs, self-determination (choice), social relatedness, and personal meaning or value (Haussler & Hoffmann, 2002). For example, to enhance an individual's self-determination, teachers can provide students options for how to pursue or demonstrate their learning; and to help an individual realize the meaningfulness of issues, educators can emphasize why the content matters in everyday life (Schiefele, 2009). Civic issues, which include questions related to public spaces (e.g., parks, roads) and the distribution of resources (e.g., healthcare, school funding), can be especially meaningful engaging for young people because they relate closely to their lives (Levine, 2007; Levy et al., 2016).

Researchers in social studies education have found that examining and discussing public issues with peers can enhance engagement in those issues (e.g., Hess, 2009; Levy, 2013; Levy et al., 2017), and as the review below indicates, exploring science-related public issues can strengthen students’ science content knowledge (Eastwood et al., 2013), understanding of scientific process (Brossard et al., 2005), and beliefs that science is related to their lives (Parchmann et al., 2006). Many explorations of public issues include collaborative inquiry-based learning (Levine, 2013; Newmann et al., 2016), and science coursework can productively integrate such activities. Indeed, Blumenfeld et al. (2006) found that inquiry-based science
curricula, which pose authentic questions and require the selection and analysis of data as well as peer collaboration, can strengthen students’ cognitive engagement in science.

Thus, research in two distinct fields comports with more general research on motivation, which suggests that when individuals have opportunities to conceptualize the meaningfulness of issues (Haussler & Hoffmann, 2002) and have emotionally positive interactions with others related to those issues (Silvia, 2006), they engage in learning these issues more readily. However, as we note below, there are unanswered questions about how these practices in science education can simultaneously support motivation to learn science, effective civic engagement, and the development of valuable scientific understandings.

3.3 Strengthening civil society and public policy

We believe that CSE can strengthen science-related civil society and public policy, and leading scholars in science education have also supported this notion. After all, civic participation of well-informed youth can and does contribute to positive change, such as the restoration of urban forests and the preservation of wetlands (e.g., Earth Island Staff, 2002). Rudolph and Horibe (2016) argue that science education can and should prepare young people to actively engage in science-related public issues by fostering the knowledge and skills necessary for both the production and use of scientific knowledge. Likewise, Feinstein (2011) contends that an essential rationale for generating scientific literacy is its “usefulness,” emphasizing that youth should learn to become “competent outsiders” who understand the social and political relevance of their science learning.

Others take even stronger stances. For example, Hodson (2003) argues that to address 21st century challenges, science curricula should have sociopolitical action as a central goal.
Citing a similar rationale, Bazzul (2015) advocates a science education that disrupts social hierarchies by consider varying cultural perspectives on ecology and scientific sense-making.

Echoing these science education scholars’ arguments, leaders in civic learning have noted that competent participants in democratic systems must understand public issues in numerous domains (e.g., Youniss et al., 2002), such as science. And over a century ago, Dewey (1910) made a similar point, noting that education writ large should aim to build a stronger, more informed democratic society, with civic participants equipped to address its present social challenges (Dewey, 1916; Rudolph, 2014).

Furthermore, numerous researchers and advocates have argued for regularly integrating civic issues into coursework in science. For example, leaders of environmental education organizations, governmental institutions, and nonprofit groups have repeatedly emphasized the need for broad civic and political involvement to address environmental challenges (e.g., Flowers & Chodkiewicz, 2009; Huckle, 2009; UNESCO, 1978). Lester Brown (2011), author and president of the nonpartisan Earth Policy Institute, contends that “restructuring the global economy means becoming politically active, working for the needed changes, as the grassroots campaign against coal-fired power plants is doing” (p. 200).

And since the 1960s, environmental educators (Government of Canada, 2002; Levy & Zint, 2013; Stapp, 1969; UNESCO, 1978) have emphasized the need for youth to learn about both the scientific basis of environmental problems and how to support and develop policy-based solutions. Such problems, they contend, are widely dispersed, and individuals need to advocate for sustainable policies and become involved in processes that will address their local needs. As Bencze and Carter (2011) note, if school science courses would contextualize scientific
environmental challenges in their societal context, they could begin to prepare youth to help address these issues.

4 | Prior Research on CSE Practices

Several strands of research have examined learning experiences and outcomes related to CSE (see Table 1), and we organize these into three broad categories that capture the major trends and relate to the categories described above (see Table 3). First, we summarize research on socioscientific issues in education, which explores how educators can support students’ understanding of the ethical and social dilemmas embedded in scientific endeavors. We consider this an important element of foundational CSE. Then we synthesize studies of citizen science, also known as public participation in science research (PPSR), an age-old practice that invites broad participation in the process of scientific inquiry, which we consider one type of exploratory CSE. Next, we describe research on students’ engagement in guided science-oriented civic action, a key area of purposefully active CSE. Whereas most of these studies included middle and high school student participants, others examined the learning and experiences of adults and elementary school students.

4.1 Research on learning about socioscientific issues (SSIs)

For over three decades, researchers in science education have explored how science curricula can incorporate the social contexts and applications of science to enhance scientific understanding. This effort began in the 1980s with a broad, somewhat vague focus on science, technology, and society (STS). A review of this early line of research suggests that STS approaches supported secondary students’ development of scientific knowledge and positive attitudes towards school science (Bennett et al., 2007). Nonetheless, several scholars began to
### Table 3 | Outcomes of CSE Practices

| CSE Practice                                           | Key Outcomes                                      | Study Author(s)                                      |
|--------------------------------------------------------|---------------------------------------------------|------------------------------------------------------|
| SSI Explorations and Discussions (A Type of Foundational CSE) | Science Content Knowledge                         | Klosterman & Sadler, 2010                           |
|                                                        |                                                   | Sadler et al., 2013                                  |
|                                                        | Interdisciplinary Understanding of Inquiry        | Eastwood et al., 2013                                |
|                                                        | Argumentation Skills                              | Khishfe, 2014                                        |
|                                                        |                                                   | Acar, Turkmen, & Roychoudhury, 2010                  |
|                                                        | Relevance of Science to Everyday Life             | Parchmann et al., 2006                               |
|                                                        |                                                   | Pelch & McConnell, 2017                              |
|                                                        | Future-Scaffolding Skills                         | Levrini et al., 2020                                 |
| Public Participation in Science Research               | Understanding Scientific Process                  | Brossard, Lewenstein, & Bonney, 2005                 |
| (A Type of Exploratory CSE)                            | Science Knowledge                                 | Bonney, Phillips, Ballard, & Enck, 2016              |
|                                                        | Feelings of Community Connectedness               | Overdesvest, Orr, & Stepenuck, 2004                  |
|                                                        | Appreciation of Ecosystem                         | Haywood, 2016                                        |
|                                                        | Interest in Science                               | Trumbull, Bonney, Bascom, & Cabral, 2000             |
|                                                        |                                                   | Wallace & Bodzin, 2017                               |
| Guided Science-Oriented Civic Action                  | Commitment to Conducting Research-Informed Activism | Bencze et al., 2012                                 |
| (A Type of Purposefully Active CSE)                    | Citizenship Action Skills                         | Culen and Volk, 2000                                 |
|                                                        | Science-Related Career Goals                      | Calabrese Barton, Birmingham, Sat, Tan, & Calabrese Barton, 2013 |
|                                                        | Critical Consciousness                             | Schindel Dimick, 2016                                |
|                                                        | Knowledge of Environmental Problems               | Sellman and Bogner, 2013                             |

Researchers have found that SSI approaches have a variety of positive effects on students’ conceptual learning in science. For example, Klosterman and Sadler (2010) studied...
high school chemistry and environmental science courses that included a three-week unit on climate change that explored both scientific topics and related political controversies. They found substantial gains in students’ science content knowledge during the unit. In a separate study, Sadler and several colleagues (2013) investigated students’ biology learning through a video game during which they assumed the role of a biologist attempting to diagnose the causes of an emerging epidemic. With a sample of over 600 students at various levels with 10 different teachers, findings indicated substantial content knowledge gains for students across all levels, especially the lower tracks. SSI approaches have also been studied at the college level. Eastwood et al. (2013) compared students in an SSI-focused undergraduate biology major and those in a traditional biology major. Whereas both groups developed similar understandings of scientific inquiry, survey results indicated that the SSI context supported more nuanced, interdisciplinary understandings of inquiry.

Whereas the latter studies focused on conceptual learning, others have explored how certain SSI approaches can help young people to develop important science-related skills. For example, Khishfe (2014) examined student learning through their engagement in a curriculum about water quality, which included explorations and discussions about how humans make decisions to manage risks. She found that all participants developed an increased understanding of the nature of science (NOS) and that those who had explicit instruction in argumentation also developed greater argumentation practices, which they integrated into their NOS understandings.

Other studies have examined students’ reasoning about SSIs (Tsai, 2019; Wu & Tsai, 2007) and the variety of teacher practices and challenges involved in facilitating students’ SSI argumentation skills (Acar et al., 2010). One useful study in Germany found that integrating SSIs into chemistry coursework helped students to perceive science as more interesting and relevant
to their lives (Parchmann et al., 2006). Similarly, Pelch and McConnell (2017) found that repeated and explicit exposure to socioscientific issues positively influences students' attitudes about science and their perceptions on the relevance of science. This study involved 310 students enrolled in a physical geology course with an active learning format where students frequently watched videos and participated in collaborative activities with their peers (e.g., think-pair-share activities).

One recent study published in this journal explored students’ experiences in a climate change curriculum that enabled them to consider various possible future scenarios, including scientific and societal dimensions (Levrini et al., 2020). After learning about climate change, students were introduced to the “cone of possible, plausible, desirable future scenarios” and asked to entertain possible courses of action that they could take as responsible, active citizens faced with a variety of climatic futures. The study, which analyzed essays, interviews, and projects of 24 students exposed to this curriculum in three European countries, found that participants’ views about the future widened, that is, they began feeling that the future was more approachable as they developed future-scaffolding skills and a sense of agency.

Despite the plethora of evidence that studying SSIs supports students’ learning and curiosity in science (Tirri et al., 2012), few studies have examined how and the extent to which SSI approaches support students’ motivation to learn science or become civically engaged. One exception is the work of Hewitt et al. (2019). They examined the effects of a socioscientific issues curriculum relative to a control curriculum on student motivation in a large introductory biology course for life science majors (n = 1032). Using hierarchical linear modeling, they found that the SSI group had a significant increase in motivation, indicating greater self-determination in students experiencing an SSI-based curriculum, which could lead to greater student success.
and persistence. Qualitative data suggested that this increased motivation of the SSI group relative to the control group was due to enhanced feelings of relatedness experienced by students. Although the participants in this study were college students, these findings and others suggest that SSIs may be valuable for boosting motivation to learn science in a variety of settings.

4.2 Research on learning through “citizen science”

Another trend related to CSE is the “citizen science” approach, also referred to as public participation in science research (PPSR). This approach involves nonprofessional scientists, including students, collecting, and analyzing data on scientific issues within the public domain, such as bird migration patterns and water quality. This process has a long history extending back many centuries, including Japanese court diarists who noted the dates of cherry blossoms and 17th century professional scientists who recruited non-scientists to help them make observations and collect specimens of the natural environment (Miller-Rushing et al., 2012). Such collaborations have continued, contributing to some of the largest data collections in history. For example, the National Weather Service Cooperative Observer Program (NSW-COOP) has collected records of US weather from 1890 to the present. In recent decades, advances in communication, transportation, and computing have facilitated broader participation in citizen science.

Scholars have argued that these experiences with hands-on, authentic data collection and analysis can enhance science learning by making science more tangible and relevant for participants (e.g., Jenkins, 2011), and evidence supports this argument. In a study of the COASST program, in which volunteers monitor local beaches for beached birds and marine debris, Haywood (2016) found a variety of benefits from participation, including social
connections, greater awareness and appreciation of the ecosystem, a sense of satisfaction, and
greater mental and physical health. Some participants described feeling a sense of ownership of
the beaches they monitored, and one even mentioned dreaming about peaceful encounters with
wildlife. Similarly, researchers found that adult participants in a stream monitoring program in
Wisconsin experienced increased political engagement and feelings of community connectedness
(Overdesvest et al., 2004).

Some studies also indicate the PPSR can enhance participants’ scientific knowledge. For
example, in a study of 798 data collectors for The Bird Network, who gathered and shared
information on birds’ nest boxes and their inhabitants, researchers found that participants
developed a greater understanding of bird biology and the scientific process as a whole (Brossard
et al., 2005). However, a review of numerous studies of citizen science projects found that such
programs, while contributing substantially to scientific undertakings and questions, have limited
but positive outcomes for participants’ science knowledge (Bonney et al., 2016).

Despite these helpful findings, few studies have thoroughly explored the attitudinal shifts
that participants experience during their participation in citizen science projects. Groulx (2017)
published a literature review identifying 23 different outcomes that studies of citizen science
have examined. Whereas the majority of these studies examined knowledge outcomes, only six
percent studied changes in motivation and three percent explored the facilitation of democratic
participation in societal decisions. And although there is some evidence that participating in
citizen science projects can support an interest in science (Trumbull et al., 2000), little rigorous
research has examined how and if such experiences actually generate this interest among youth.

Most citizen science programs work with adult volunteers, who are already very
motivated and interested in science (e.g., Martin, 2017). Some teachers have recently begun to
integrate citizen science into their classrooms (Cooper, 2012), but students’ learning in such required citizen science curricula has rarely been examined. In one example, Wallace and Bodzin (2017) followed ninth-grade students as they engaged with a mobile technology app, LeafSnap, with the intent of understanding phenological changes related to global warming. While students reported being more interested in science and technology as a result, they were not asked about future behaviors or public, civic actions. Most curriculum-based citizen science program evaluations have focused on whether students gained content knowledge, improved their science practices, or increased their level of interest in science (Bonney et al., 2016). Additional work needs to be done to understand how incorporating citizen science into a classroom setting might positively affect students’ civic engagement.

4.3 Research on guided science-oriented civic action

As researchers have explored the educational outcomes involved in citizen science and SSI approaches, they have also begun to examine how engaging in guided science-oriented civic action can affect young people's development. For example, Bencze et al. (2012), drawing on their STEPWISE (Science & Technology Education Promoting Wellbeing for Individuals, Societies, & Environments) framework, worked collaboratively with teachers who guided students to identify science-related civic challenges, design action steps to address them, and implement those action steps. Their qualitative study documented numerous student-initiated projects, such as researching and publicizing water quality data, and found that youth in these courses developed a greater commitment to conducting research-informed activism. Raising awareness (through posters, banners, and videos) about how to address environmental problems was especially meaningful for students.
Several other studies have examined the outcomes of students’ experiences related to their local environments. In research with over 100 German high school students, Sellmann and Bogner (2013) found that hands-on learning experiences in a botanical garden enhanced students’ knowledge about climate change and its impacts, both in the short-term and long-term. Likewise, Krasny and Tidball’s (2009) study of community gardening suggests that such experiences can foster multiple types of learning, including not only scientific knowledge but also greater awareness of food sources and connections to nature. And Culen and Volk (2000) found that middle school science students who were guided through the “issue investigation-evaluation and action process” with their local wetland developed greater knowledge of both ecological foundations and citizenship action skills. Thus, purposefully participating in efforts to care for the local environment can have a variety of positive learning outcomes.

Some researchers have explored how more direct science-related activism can affect students’ development. For example, in the GET City (Green Energy Technology in the City) extracurricular program, low-income urban youth had opportunities to become “community science experts” by exploring local energy needs and options and then communicating findings to their community. These experiences enhanced participants’ interests and aspirations in pursuing careers in science and engineering (Calabrese Barton et al., 2013). Furthermore, Birmingham and Calabrese Barton (2014) found that when some of these middle school youth organized a “green carnival,” they merged their place-based understandings with core science ideas, which enabled them to alter their perceptions of the relationship between science and their community. Similarly, in a study of urban high school students restoring an urban park, Schindel Dimick (2016) found that youth can develop a sense of critical consciousness by beginning to envision how current patterns of development and infrastructure could be different.
Thus, prior research shows that students can learn a great deal from their guided experiences in science-oriented civic action. However, studies have not closely examined participants’ motivations to become engaged in learning science or to participate in civic issues. We believe that considering previous scholarship and research focused on fostering informed civic engagement could strengthen future work in CSE.

5 | Prior Research on Fostering Informed Civic Engagement

Scholars of education have long been concerned about preparing young people to participate in civic life. Over a century ago, Dewey (1899/2008) noted that “Democracy has to be born anew with each generation, and education is its midwife.” Around the same time, the National Council for the Social Studies (NCSS) was founded with the key purpose of “obtaining the maximum results in education for citizenship” (A National Council, p. 144, as cited in Nelson, 1995). Since then, educators have designed numerous methods to prepare young people for their future roles as democratic participants, and in the past six decades, researchers have identified the types of experiences that are especially helpful for fostering knowledge, values, and skills that facilitate active participation in democratic life. These findings, reported in the Handbook of Research on Civic Engagement in Youth (Sherrod et al., 2010) and other scholarly outlets, are quite numerous, and in this section, we summarize key findings that seem most relevant to CSE (see Table 4).

First, exploring and discussing public issues supports various aspects of informed civic engagement. For example, Kenski and Stroud (2010) survey of tens of thousands of people explored how talking about politics affects political efficacy, an excellent predictor of political participation (Becker, 2004; Paulsen, 1991). They found that such exchanges have a greater
Table 4 | Experiences that Support Informed Civic Engagement

| Experience Category                        | Key Outcomes                  | Study Author(s)                                                                 |
|-------------------------------------------|-------------------------------|--------------------------------------------------------------------------------|
| Exploring and Discussing Public Issues    | Civic Participation Capacities| Condon, 2015                                                                   |
|                                          | Political Tolerance           | Avery, Bird, Johnstone, Sullivan, & Thalhammer, 1992                          |
|                                          | Deep Content Learning         | Newmann, King, & Carmichael, 2007                                             |
|                                          | Political interest            | Levy, Solomon, & Collet-Gildard, 2016                                          |
|                                          | Political efficacy            | Morrell, 2005; Kenski & Stroud, 2006; Wells & Dudash, 2007                    |
| Participating in Democratic Processes     | Political Efficacy            | Ikeda, Kobayashi, & Hoshimoto, 2008; Levy, 2013, 2018                         |
|                                          | Political Open-Mindedness     | Levy, Babb-Guerra, Batt, & Owczarek, 2019                                     |
|                                          | Civic Competencies            | LeCompte, Blevins, & Riggers-Piehl, 2020                                       |
|                                          | Political Interest            | Ganzler, 2010; Mariani, 2007                                                   |
|                                          | Content Learning              | Frederking, 2005                                                               |
| Communicating Publically about Civic Issues| Expected Post-High School Activism | Andolina & Conklin, 2018, 2020                                               |
|                                          | Political Interest            | Levy et al., 2016                                                             |
|                                          | Protesting                    | Vissers & Stolle, 2014                                                        |

impact on political efficacy than reading newspapers, watching television news, or listening to political talk radio, controlling for race and socioeconomic factors. Analyses of focus groups by Wells and Dudash (2007) had similar findings. Likewise, Morrell's (2005) study found that students who aimed for consensus through deliberation gained greater political efficacy than those who could vote independently on an issue.

Examining the importance of verbal skills, Condon (2015) analyzed data from the National Education Longitudinal Study, finding that verbal skills in secondary school (which can be fostered through classroom discussion) were a good predictor of both voter turnout and volunteering for civic organizations. Also, one study of over 300 high school students indicated
that discussing political issues was a strong predictor of political interest development, controlling for GPA, SES, and other background variables (Levy et al., 2016). In short, research indicates that teachers can support young people's civic engagement by providing and guiding experiences that enable them to explore and verbally discuss public issues.

Another set of experiences known to support civic engagement is participation in democratic processes. As Mill (1859) argued, political participation leads to an “active” character, and evidence supports this theory. For example, a study of political behavior in 22 countries found that voting leads to higher levels of external political efficacy by improving the “cognitive articulation” of the governmental system (Ikeda et al., 2008). Other research indicates that when one votes for a winning candidate, political efficacy increases are substantial (Bowler & Donovan, 2002; Clarke & Acock, 1989). Beyond attitudes, one recent study found that students who participated in an action civics program in their community developed numerous civic competencies, including the ability to run a meeting, write an opinion letter, or get others to care about a problem (LeCompte et al., 2020). This study all suggests that pursuing and/or achieving one's goals through civic or political action can be empowering and enhance young people's capacities.

In addition, numerous studies indicate that civic engagement develops when individuals engage in political simulations. For example, Ganzler (2010) and Levy et al. (2019) studied an extended, semester-long political simulation for high school students and found that the program boosted a wide range of pro-civic attitudes, including political interest and political open-mindedness. Likewise, Stroupe and Sabato (2004) found that secondary school students participating in mock elections with accompanying curricula gained greater political efficacy, and Bernstein (2008) found that college students who completed a political simulation made
significant gains in both political attention and political efficacy. Thus, as theories of social learning (e.g., Bandura, 1997) suggest, engaging in certain activities can positively affect one's attitudes towards those activities, and this is especially true if those experiences include positive emotions (Silvia, 2006).

A third category of activities that can enhance young people's civic engagement is communicating publicly, both online and offline, about civic issues. For example, researchers found that students who blogged online about political issues for an hour per week for one semester developed greater political interest, internal political efficacy, and self-efficacy for writing about politics than students who did not share their political ideas in this way (Levy et al., 2015). And another study of 500 undergraduates indicates that using one's political voice on Facebook (e.g., commenting, sharing) is a good predictor of other online and offline forms of political participation (Vissers & Stolle, 2014). Similarly, researchers recently examined the effects of Project Soapbox, a five-lesson curriculum that guides students to select and explore public issue and then make a speech about that issue to one's classmates. Participants in the program, primarily nonwhite Chicago youth, became more civically engaged in various ways—indicating a greater willingness to contact government officials, express one's opinions via news media, and raise awareness about issues via social media (Andolina & Conklin, 2018).

Thus, researchers have identified several types of experiences that enhance young people's likelihood of future democratic participation. Some science educators have integrated these and similar practices into their classrooms (see Table 3), and we contend that expanding these types of experiences could be an effective and exciting way to enhance youth civic engagement, scientific learning, and informed democratic participation overall.
Uncertainties and Future Directions in CSE

The main argument of this paper is that CSE has the potential to have a tremendously positive impact on science education, civic engagement, and civil society more broadly. And although there has been substantial research on CSE practices, many unanswered questions remain. In this section, we summarize the evidence to support our main argument and suggest future directions for research and practice.

Overall, prior research suggests that CSE has can help to address some major practical challenges that we face as a society—namely, limited motivation in science (Osborne et al., 2003) and low youth civic engagement (Center for Information and Research on Civic Learning & Engagement, 2020a, 2020b). Integrating civic issues into science coursework and highlighting the relevance of science to students’ lives can enhance their motivation to learn science, a strong predictor of persistence and learning (Renninger & Hidi, 2016), and can also provide opportunities for youth to explore and contribute to their communities (Bencze et al., 2012). Drawing on the research described in this paper, Table 5 summarizes the outcomes that might be expected from foundational, exploratory, and purposefully active CSE.

As the research on teaching SSIs show, foundational CSE experiences can support students’ scientific knowledge and skills (Khishfe, 2014; Sadler et al., 2013) and their view of science as relevant to their everyday lives (Pelch & McConnell, 2017). Likewise, civic education research suggests that such learning experiences, if involving sufficient discussion or deliberation, can support the development of students’ political interest and efficacy (Levy, 2011, 2013; Levy et al., 2016; Morrell, 2005). There are many resources available to support teachers’ enactment of classroom discussions of public issues, such as those offered by Facing History and Ourselves, and science educators interested in guiding these experiences should
explore some of the discussion structures and professional development opportunities available.

In addition, we encourage researchers to examine how foundational CSE (including even direct instruction approaches) can support motivation in science and civic engagement, how educators

Table 5 | Examples and Expected Outcomes of Civic Science Education

| CSE Category       | Curriculum Examples                                                                 | Expected Outcomes                                      |
|--------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------|
| Foundational       | Reading about and discussing the impact of climate change                           | Argumentation Skills                                    |
|                    |                                                                                     | Science Content Knowledge                               |
|                    | Watching videos about deforestation and writing about its causes, effects, and potential solutions | Civic Content Knowledge                                 |
|                    |                                                                                     | Civic & Political Interest\textsuperscript{m}           |
|                    |                                                                                     | Civic & Political Efficacy\textsuperscript{m}           |
|                    |                                                                                     | Self-Efficacy in Science Knowledge\textsuperscript{m}   |
| Exploratory        | Collecting and analyzing data about changing precipitation patterns and its impact on communities | Inquiry Skills                                          |
|                    |                                                                                     | Science Content Knowledge                               |
|                    | Observe, analyze, and write about satellite data tracking deforestation              | Science Process Knowledge                               |
|                    |                                                                                     | Civic Content Knowledge                                 |
|                    |                                                                                     | Interest in Science\textsuperscript{m}                  |
|                    |                                                                                     | Self-Efficacy in Science Skills\textsuperscript{m}      |
| Purposefully Active| Designing and enacting a way to communicate with policymakers about how to address flooding or drought | Participatory Skills                                    |
|                    | Creating and sharing a video or infographic (on social media) about deforestation and what we can do to reduce it | Political & Civic Efficacy\textsuperscript{m}           |
|                    |                                                                                     | Political & Civic Interest\textsuperscript{m}           |
|                    |                                                                                     | Informed Civic Participation                            |
|                    |                                                                                     | Science-Related Career Goals\textsuperscript{m}         |
|                    |                                                                                     | Scientific Knowledge                                     |
|                    |                                                                                     | Critical Consciousness                                   |
|                    |                                                                                     | Self-Efficacy in Science Knowledge\textsuperscript{m}   |
|                    |                                                                                     | Broader Social/Community Impacts\textsuperscript{m}     |

\textit{Note.} All three categories of CSE can and should include curricular elements that involve at least two of the four key drivers of intrinsic motivation: (1) meaningfulness/value, (2) autonomy/choice, (3) relatedness/social interaction, and (4) competence/self-efficacy development. For example, many potential CSE topics, such as water quality and public health, can be personally meaningful for students because they affect their lives or those of their family, friends, and communities.

\textsuperscript{m}Outcomes that are closely related to the development of intrinsic motivation in the relevant domain (i.e., science or civic participation)
learn to engage in such practices, and the best ways to integrate these practices into various educational contexts. Given persistent inequities in education (e.g., Duncan & Murnane, 2011), it is especially important to consider how students from low-income, segregated schools can most benefit from CSE.

Exploratory CSE also has the potential to support important learning outcomes. Public participation in science research experiences, for example, can support students’ understanding of scientific processes (Brossard et al., 2005), interest in science (e.g., Wallace & Bodzin, 2017), feelings of community connectedness (Overdesvest et al., 2004), science knowledge (Bonney et al., 2016), and appreciation of ecosystems (Haywood, 2016). Furthermore, critical civic inquiry can strengthen participants’ civic efficacy (Hipolito-Delgado & Zion, 2017), and structured inquiry-based learning about social and civic issues can build students’ knowledge of the topics of they explore (Grant et al., 2017). Though current standards are indeed imperfect (Feinstein & Kirchgasler, 2015), several influential standards documents, including the Next Generation Science Standards (2013), the C3 (College, Career, & Civic Life) Framework of the National Council for the Social Studies, and the Common Core Standards (NGA & CCSSO, 2010), all emphasize inquiry-based learning as a vital instructional element. Educators interested in pursuing these practices can access numerous helpful resources that they can adapt to serve the needs of their own contexts and CSE-related objectives.

Nonetheless, we have only limited understanding of how guided inquiry experiences in CSE could support learning towards certain standards, and researchers should explore this question. Commonly taught science topics that would fit well with exploratory approaches include climate and weather, ecological systems, public health, water systems, and geoscience. Like other forms of instruction, CSE curricula and experiences could develop and improve
through design-based studies (Barab & Squire, 2004) and then, once successful at meeting learning goals of researchers, educators, and policymakers, could expand through design-based implementation research (Penuel & Fishman, 2012), potentially having a broad impact on learning and civic life.

Whereas foundational and exploratory CSE can foster the development of students’ knowledge, skills, and values in scientific and civic issues, purposefully active CSE can provide powerful, memorable experiences that could positively impact not only participants themselves but also civil society more broadly. Political theorists have long argued that discussions in the public sphere can influence democratic decision-making (e.g., Habermas, 1992), and with the internet’s expansion of the public sphere, there are an unprecedented number of participatory opportunities on issues related to personal values, economics, and science, among other things (e.g., Edgerly et al., 2008). Evidence indicates that guided science-oriented civic action can foster students’ citizenship action skills (Culen & Volk, 2000), knowledge of environmental problems (Sellmann & Bogner 2013), and commitment to conducting research-informed activism (Bencze et al., 2012), and participating actively in the democratic process can enhance participants’ political efficacy (Levy, 2013, 2018), political interest (Ganzler, 2010), civic competencies (LeCompte et al., 2020), and content learning (Frederking, 2005).

There are numerous curricular models that scaffold students’ engagement in purposeful, informed civic action, such as those developed by Earth Force and Generation Citizen, many of which are freely available online. These programs and others have guided young people's contributions to their communities, such as conserving watersheds, preventing overfishing, and developing community farms (e.g., Earth Island Staff, 2002; Kim et al., n.d.; Sevigny, 2021). Furthermore, hundreds of educators have joined a systematic reform effort called Science
Education for New Civic Engagements and Responsibilities (SENCER). This NSF-funded program aims to integrate civic issues into undergraduate science education and has generated numerous faculty discussions, workshops, and course revisions. Researchers have documented college educators’ innovative practices (e.g., Bachofer, 2010; Masthay, 2010), such as chemistry students studying the redevelopment of a Superfund site. Few studies have closely examined students’ learning outcomes in SENCER, Earth Force, or other purposefully active CSE efforts, and it would be valuable for empirical researchers to explore how such programs can best enhance both students’ civic engagement and their motivation in science, attending to variations in content, forms of civic participation, and participant populations. Findings in this domain could provide insights about how purposefully active CSE can strengthen scientific learning as a whole and could persuade educators to engage students in experiences that could strengthen learning as well as society at large.

In addition to conducting studies that explore how foundational, exploratory, and purposefully active CSE can enhance civic engagement and motivation to learn science, scholars, and leaders in science education ought to consider what students should learn about the role of science in society (Rudolph & Horibe, 2016): How should science be used in settling science-related public decisions? What should the public’s role be in overseeing scientific endeavors and establishing funding priorities? What would be the best processes and mechanisms for fostering productive interactions among scientists, the public, and policymakers? These types of macro-level discussions are vital at a time of rapid technological and social change and could inform the direction of science education during these uncertain times. (Just as these issues are important for educators and scholars, they could also be meaningful for student deliberation, and researchers could examine the outcomes of students’ explorations of these issues.)
Finally, educational standards and assessments should shift by adding more emphasis on CSE and civic issues more broadly. As we note in the introduction, the current NGSS standards acknowledge the value of civic engagement to some extent. However, the standards primarily emphasize the role of citizen as arguer (Practice 7: Engaging in argument from evidence).\(^2\) These standards say little about students participating in civic life, exploring the role of science in policymaking, sharing one's scientific knowledge with others (including school and civic leaders), or designing scientific projects that serve the public interest. Such a narrow view of civic engagement presumes that students will enter a society based solely on reason, uninfluenced by political interests or power struggles, with a level and equitable field of social existence in which all are given a fair hearing.

However, real-world democratic participation in decision-making is a much more complex and messy endeavor (Senecah, 2004) that requires, among other things, access (availability of adequate resources and opportunities for public involvement and participation), standing (civic legitimacy in the form of respect and esteem of stakeholders’ perspectives), and influence (opportunity to effectively shape the scope of alternatives, decision criteria, and ultimate responses). Arguing effectively may be of little consequence if the arguer has a low social status or lacks equitable access to argumentative forums. Greater attention to these socio-political complexities and inequities is needed if science learners are to indeed become prepared to realize their full civic potential. We encourage policymakers, scholars, and educators to

\(^2\) Specifically, NGSS indicates that, in Grades 9-12, students should: "Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence, challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining additional information required to resolve contradictions" (NGSS Lead States, 2013).
consider a vision of CSE that would facilitate young people's active engagement in science-related public issues.

7 Conclusion

Our world faces numerous science-related public challenges. We encourage researchers in science education, civic engagement, and motivation psychology either to collaborate directly or to attend closely to one another's ideas to develop successful and scalable educational programs that will enable future generations to democratically address these challenges. Because these problems are numerous and widely dispersed, addressing them will require ongoing broad public engagement and exploration. Yet we have hope. Preparing young people to become well-informed civic participants can strengthen our resilience amidst complex public problems, and researchers can help to identify, develop, and understand the most effective ways of doing so.

Data availability statement: The data that support the findings of this study are available from the corresponding author upon reasonable request
References

Acar, O., Turkmen, L., & Roychoudhury, A. (2010). Student difficulties in socioscientific argumentation and decision-making research findings: Crossing the borders of two research lines. *International Journal of Science Education, 32*(9), 1191-1206.

Amgen Foundation. (2016). Students on STEM: Methodology. Available online at http://changetheequation.org/students-stem-methodology

Andolina, M. W. & Conklin, H. G. (2018). Speaking with confidence and listening with empathy: The impact of Project Soapbox on high school students. *Theory & Research in Social Education 46* (3), 374-409.

Andolina, M., & Conklin, H. G. (2020). Fostering democratic and social-emotional learning in action civics programming: Factors that shape students’ learning from Project Soapbox. *American Educational Research Journal, 57*, 1203-1240.

Árnason, V. (2012). Scientific citizenship in a democratic society. *Public Understanding of Science, 22*(8), 927-940.

Aronowitz, S. (1988). *Science as power: Discourse and ideology in modern society.* Minneapolis, USA: University of Minnesota Press.

Avery, P. G., Bird, K., Johnstone, S., Sullivan, J. L., & Thalhammer, K. (1992). Exploring political tolerance with adolescents. *Theory & Researcher in Social Education, 20*, 386-420.

Bachofer, S. J. (2010). Studying the redevelopment for a superfund site: An integrated general science curriculum paying added dividends. In Sheardy (Ed.), *Science Education and Civic Engagement: The SENCER Approach.* Washington, DC: American Chemical Society.
Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York, NY: Freeman.

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *Journal of the Learning Sciences, 13*(1), 1–14.

Bazzul, J. (2015). Towards a Politicized Notion of Citizenship for Science Education: Engaging the Social Through Dissensus. *Canadian Journal of Science, Mathematics & Technology Education, 15*(3), 221-233.

Becker, R. (2004). Political efficacy and voter turnout in East and West Germany. *Swiss Political Science Review, 11*(1), 57-86.

Bencze, L. (2019). STSE Education: Learning about relationships among fields of science & technology and societies & environments. Available online at https://webspace.oise.utoronto.ca/~benczela/STSEEd.html

Bencze, L., & Carter, L. (2011). Globalizing Students Acting for the Common Good. *Journal Of Research In Science Teaching, 48*(6), 648-669.

Bencze, L. l., Sperling, E., & Carter, L. (2012). Students' research-informed socioscientific activism: Revisions for a sustainable future. *Research in Science Education, 42*(1), 129-148.

Bennett, J., Lubben, F., & Hogarth, S. (2007). Bringing science to life: A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. *Science Education, 91*(3), 347-370.

Bernstein, J. L. (2008). Cultivating civic competence: simulation and skill-building in an introductory government class. *Journal of Political Science Education, 4*(1), 1-20.

Birmingham, D., & Calabrese Barton, A. (2014). Putting on a green carnival: Youth taking
educated action on socioscientific issues. *Journal of Research in Science Teaching, 51*(3), 286-314.

Bishop, G., & Low, R. (2004). Exploring young Canadians’ attitudes towards government, politics and community. Paper presented at the research seminar on the *Political Engagement of Canadian Youth*, Ottawa, Ontario, Canada.

Blumenfeld, P. C., Kempler, T. M., & Krajcik, J. S. (2006). Motivation and cognitive engagement in learning environments. *Cambridge Handbook of the Learning Sciences*.

Bonney, R., Phillips, T. B., Ballard, H. L., & Enck, J. W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science, 25*(1), 2-16.

Bowler, S. & Donovan, T. (2002). Democracy, institutions and attitudes about citizen influence on government. *British Journal of Political Science, 32*(2), 371-390.

Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design*. Cambridge, MA: Harvard University Press.

Brossard, D., Lewenstein, B., & Bonney, R. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education, 27*(9), 1099-1121.

Brown, L.R. (2011). *World on the edge: How to prevent environmental and economic collapse*. New York, NY: Norton.

Calabrese Barton, A., Birmingham, D., Sato, T., Tan, E., & Calabrese Barton, S. (2013, Fall). Youth as community science experts in green energy technologies. *Afterschool Matters*, 25-32.
Carpenter, Z. (2012, November 7). Despite concerns, young people tuned in and turned out in 2012. *The Nation.* Available online at http://www.thenation.com/article/171111/despite-concerns-young-voters-tuned-and-turned-out-2012#

Center for Information and Research on Civic Learning and Engagement (2016). Millennials after 2016: Post-election poll analysis. Retrieved from https://circle.tufts.edu/sites/default/files/2019-12/millennials_after_2016_0.pdf

Center for Information and Research on Civic Learning and Engagement (2020a). *Half of youth voted in 2020, and 11-point increase from 2016.* Retrieved from https://circle.tufts.edu/latest-research/half-youth-voted-2020-11-point-increase-2016

Center for Information and Research on Civic Learning & Engagement (2020b). National Youth Voter Turnout. Retrieved from https://circle.tufts.edu/2020-election-center

Checkoway, B. & Aldana, A. (2013). Four forms of youth civic engagement for diverse democracy. *Children and Youth Services Review, 35*, 1894-1899.

Clark, F., & Illman, D. L. (2001). Dimensions of civic science. *Science Communication, 23*(1), 5-27.

Clarke, H.D., & Acock, A.C. (1989). National elections and political attitudes: The case of political efficacy. *British Journal of Political Science, 19*, 551-562.

Condon, M. (2015). Voice lessons: Rethinking the relationships between education and political participation. *Political Behavior, 37*, 819-843.

Cooper, C. B. (2012). Links and distinctions among citizenship, science, and citizen science. *Democracy & Education, 20*(2), 1-4.

Culén, G.R. & Volk, T.L. (2000). Effects of extended case study on environmental behavior and associated variables in seventh- and eighth-grade students. *Journal of Environmental*
Desilver, D. (2017). U.S. students’ academic achievement still lags that of their peers in many other countries. Pew Research Center. https://www.pewresearch.org/fact

tank/2017/02/15/u-s-students-internationally-math science/%23comments

Dewey, J. (1899/2008). *The School and Society*. Cosimo Classics.

Dewey, J. (1910). Science as subject-matter and as method. *Science, 31*(787), 121-127.

Dewey, J. (1916). *Democracy and education*. New York: Free Press.

Duncan, G. J. & Murnane, R. J. (2011). *Whither opportunity?: Rising inequality, schools, and children’s life changes*. Chicago: Spencer Foundation.

Earth Island Staff. (2002). Six young champions of the Earth. *Earth Island Journal* (Spring 2002). Available online at: https://www.earthisland.org/journal/index.php/magazine/

eentry/six_young_champions_of_the_earth/

Eastwood, J., Sadler, T., Sherwood, R., & Schlegel, W. (2013). Students' Participation in an Interdisciplinary, Socioscientific Issues Based Undergraduate Human Biology Major and Their Understanding of Scientific Inquiry. *Research in Science Education, 43*(3), 1051-1078.

Edgerly, S., Vraga, E., Fung, T., Moon, T. J., Yoo, W. H., & Veenstra, A. (2008, October). Youtube as a public sphere: The proposition 8 debate. Paper presented at the conference of the Association of Internet Researchers, Milwaukee, WI.

Ekman, J., & Amnå, E. (2012). Political participation and civic engagement: Toward a new typology. *Human Affairs*, 22, 283–300.

Feinstein, N. W. (2011). Salvaging science literacy. *Science Education, 95*, 168-85.

Feinstein, N. W., & Kirchgasler, K. L. (2015). Sustainability in science education? How the Next
Generation Science Standards approach sustainability, and why it matters. *Science Education, 99*(1), 121-144.

Ferreira, J., Lennox, G.D., Gardner, T.A., Thomson, J. R., Berenguer, E., Lees, A. C., Mac Nally, R., Aragão, L. E. O. C., Ferraz, S. F. B., Louzada, J., Moura, N. G., Oliveira, V. H. F., Pardini, R., Solar, R. R. C., Vieira, I. C. G., & Barlow, J. (2018). Carbon-focused conservation may fail to protect the most biodiverse tropical forests. *Nature Climate Change 8*, 744–749.

Fitanides, H. (2020). Watershed voices: Helen Fitanides on citizen science. The Watershed Project. Available online at https://thewatershedproject.org/watershed-voices-helen fitanides-citizen-science/

Flowers, R., & A. Chodkiewicz. (2009). Local communities and schools tackling sustainability and climate change. *Australian Journal of Environmental Education, 25*, 71-81

Foucault, M. (1972). The archaeology of knowledge and the discourse on language (A.M.S. Smith, Trans.). New York, NY: Pantheon.

Frederking, B. (2005). Simulations and student learning. *Journal of Political Science Education, 1*(3), 385-393.

Ganzler, L. M. (2010). Simulated citizen: How students experience a semester length legislative simulation. (Unpublished doctoral dissertation.) University of Wisconsin—Madison, Madison, WI.

Garlick, J. A. & Levine, P. (2018). Where civics meets science: Building science for the public good through civic science. *Oral Diseases, 23*(6), 692-696.

Government of Canada. (2002). *A framework for environmental learning and sustainability in Canada*. National Library of Canada.
Grant, S. G., Swan, K., & Lee, J. (2017). *Inquiry-based practice in social studies education*. New York: Routledge.

Gregory, J., & Miller, S. (1998). *Science in public: Communication, culture, and credibility*. Cambridge, MA: Perseus Publications.

Groulx, M. (2017). A Role for Nature-Based Citizen Science in Promoting Individual and Collective Climate Change Action? A Systematic Review of Learning Outcomes. *Science Communication*, 39(1), 45-76.

Habermas, J. (1971). *Knowledge and human interests*. London: Heinemann.

Habermas, J. (1992). *The structural transformation of the public sphere*. Polity Press.

Haussler, P., & Hoffman, L. (2000). A curricular frame for physics education: Development, comparison with students; interests, and impact on students; achievement and self-concept. *Science Education, 84*(6), 689-705.

Haussler, P., & Hoffmann, L. (2002). An intervention study to enhance girls’ interest, self-concept, and achievement in physics classes. *Journal of Research in Science Teaching, 39*, 870–888.

Haywood, B. K. (2016). Beyond Data Points and Research Contributions: The Personal Meaning and Value Associated with Public Participation in Scientific Research, *International Journal of Science Education, Part B, 6*(3) 239-262.

Hess, D. E. (2009). *Controversy in the classroom: The democratic power of discussion*. New York: Routledge.

Hewitt, K.M., Bouwma-Gearhart, J., Kitada, H., Mason, R., & Kaves, L.J. (2019). Introductory biology in social context: The effects of an issues-based laboratory course on biology student motivation, *CBE—Life Sciences Education, 18*(3), 1-12.
Hipopito-Delgado, C. P. & Zion, S. (2017). Igniting the fire within marginalized youth: The role of critical civic inquiry in fostering ethnic identity and civic self-efficacy. *Urban Education*, 52(6), 699-717.

Hodson, D. (2003). Time for action: Science education for an alternative future. *International Journal of Science Education*, 25(6), 645–670.

Huckle, J. (2009). Consulting the UK ESD community on an ESD indicator to recommend to government. *Environmental Education Research*, 15(1), 1-15.

Ikeda, K., Kobayashi, T., & Hoshimoto, M. (2008). Does political participation make a difference? The relationship between political choice, civic engagement and political efficacy. *Electoral Studies*, 27(1), 77-88.

Jenkins, L. I. (2011). Using citizen science beyond teaching science content: a strategy for making science relevant to students' lives. *Cultural Studies Of Science Education*, 6(2), 501-508.

Kenski, K. & Stroud, N. J. (2010). Connections between Internet use and political efficacy, knowledge, and participation. *Journal of Broadcasting & Electronic Media*, 50(2), 173-192.

Khishfe, R. (2014). Explicit Nature of Science and Argumentation Instruction in the Context of Socioscientific Issues: An effect on student learning and transfer. *International Journal of Science Education*, 36(6), 974-1016.

Kim, L., Pereda, C., Ochoa, A., Stewart-Rowden, S., Lander, T., Linschoten, S., Lam, A., Robbins, A., Domingo, A., Nunez, E., & Casale, K. (n.d.). Building self-sustaining neighborhoods through community farms. Available online at: http://yparhub.berkeley.edu/in-action/san-lorenzo-project-eat/
Kirby, E. H., & Kawashima-Ginsberg, K. (2009, August 17). Youth vote in 2008. *Center for Information & Research on Civic Learning and Engagement*. Retrieved October 12, 2009, from http://www.civicyouth.org/PopUps/FactSheets/FS_youth_Voting_2008_updated_6.22.pdf

Klosterman, M., & Sadler, T. (2010). Multi-level assessment of scientific content knowledge gains associated with socioscientific issues-based instruction. *International Journal Of Science Education, 32*(8), 1017-1043.

Krasny, M. E., & Tidball, K. G. (2009). Community gardens as contexts for science, stewardship, and civic action learning. *Cities and the Environment (CATE), 2*(1), 8.

Kyle, W.C. (1996) Editorial: The importance of investing in human resources. *Journal of Research in Science Teaching, 33*, 1–4.

Latour, B. (2005). *Reassembling the social: An introduction to actor-network-theory*. Oxford, UK: Oxford University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

LeCompte, K., Blevins, B., & Riggers-Piehl, T. (2020). Developing civic competence through action civics: A longitudinal look at the data. *The Journal of Social Studies Research, 44*(1), 127-137.

Levine, P. (2007). *The future of democracy: Developing the next generation of American citizens*. Medford, MA: Tufts University Press.

Levine, P. (2013). *We are the ones we have been waiting for: The promise of civic renewal in America*. New York: Oxford University Press.
Levrini, O., Tasquier, G., Barelli, E., Laherto, A., Palmgren, E., Branchetti, L., & Wilson, C. (2020). Recognition and operationalization of future-scaffolding skills: Results from an empirical study of a teaching–learning module on climate change and futures thinking. *Science Education, 105*, 281-308.

Levstik, L. S., & Tyson, C. A. (2008). *Handbook of research in social studies education*. New York: Routledge.

Levy, B. L. M. (2011). Fostering cautious political efficacy through civic advocacy projects: A mixed methods case study of an innovative high school class. *Theory & Research in Social Education, 39*(2), 238-77.

Levy, B. L. M. (2013). An empirical exploration of factors related to adolescents’ political efficacy. *Educational Psychology, 33*(3), 357-390.

Levy, B. L. M. (2018). Youth developing political efficacy through social learning experiences: Becoming active participants in a supportive Model United Nations club. *Theory & Research in Social Education, 46*(3), 410-48.

Levy, B. L., Journell, W., He, Y., & Towns, B. (2015). Students blogging about politics: A study of students’ political engagement and a teacher’s pedagogy during a semester-long political blog assignment. *Computers & Education, 88*, 64-71.

Levy, B. L. M., Babb-Guerra, A., Batt, L. M., & Owczarek, W. (2019). Can education reduce political polarization?: Fostering open-minded political engagement during the Legislative Semester. *Teachers College Record, 121*(5), 1-40.

Levy, B. L. M., Collet, L., & Owenby, T. C. (2017). Generating dynamic democratic discussions: An analysis of teaching with US presidential debates. *The Social Studies, 108*(2), 39-54.
Levy, B. L. M., Solomon, B. G. & Collet-Gildard, L. (2016). Fostering political interest among youth during the 2012 presidential election: Instructional opportunities and challenges in a swing state. *Educational Researcher, 45*(9), 483-95.

Levy, B. L. M., & Zint, M.T. (2013). Towards fostering environmental political participation: Framing an agenda for environmental education research. *Environmental Education Research, 19*(5), 553-576.

Leydet, D. (2006). Citizenship. *The Stanford Encyclopedia of Philosophy*. Available at: http://plato.stanford.edu/archives/win2006/entries/citizenship/

Llewellyn, K.R., Cook, S.A., & Molina, A. (2010). Civic learning: moving from the apolitical to the socially just. *Journal of Curriculum Studies, 42*(6), 791–812.

Mariani, M. D. (2007). Connecting students to politics through a multi-class campaign simulation. *PS: Political Science and Politics, 40*(4), 789-94.

Martin, V. Y. (2017). Citizen science as a means for increasing public engagement in science: Presumption or possibility? *Science Communication, 39*(2), 142-168.

Masthay, M. B. (2010). Enhancing chemistry courses for non-majors: Implementation of simple SENCER teaching strategies at the University of Dayton. In Sheardy (Ed.), *Science Education and Civic Engagement: The SENCER Approach*. Washington, DC: American Chemical Society.

Mill, J. S. (1859). *On liberty*. London: John W. Parker and Son, West Strand.

Miller-Rushing, A., Primack, R., & Bonney, R. (2012). The history of public participation in ecological research. *Frontiers in Ecology, 10*(6), 285-90.
Morales-Doyle, D., Childress Price, T., & Chappell, M. J. (2019). Chemicals are contaminants too: Teaching appreciation and critique of science in the era of Next Generation Science Standards (NGSS). *Science Education, 103*(6), 1347-1366.

Morrell, M. E. (2005). Deliberation, democratic decision-making and internal political efficacy. *Political Behavior, 27*(1), 49-69.

National Governors Association Center for Best Practices and Council of Chief State School Officers. (2010). Common Core State Standards for the English language arts and literacy in history/social studies, science, and technical subjects. Washington DC: Author.

NAEP (National Assessment of Educational Progress) (2015). The Nation’s Report Card – Science 2015. Available online at: https://www.nationsreportcard.gov/science_2015/#acl?grade=12

Nelson, M. R. (1995). Directionless from birth: The national council for the social studies, 1921-1937. Educational Resources Information Center, document 391 & 706.

Newmann, F. M., King, M. B., & Carmichael, D. L. (2007). Authentic instruction and assessment: Common standards for rigor and relevance in teaching academic subjects. Des Moines: Iowa Department of Education.

Newmann, F.M., Carmichael, D.L. & M. Bruce King. (2016). *Authentic intellectual work: Improving teaching for rigorous learning*, Thousand Oaks, CA: Corwin Press.

NGSS (Next Generation Science Standards Consortium of Lead States) (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

OECD (Organisation for Economic Co-operation and Development). (2007). *PISA 2006. Science competencies for tomorrow’s world*. Paris: Author.
Onwu G. (2017). Towards a socially responsible science education. In B. Akpan (ed), Science education: A global perspective. Switzerland: Springer.

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education, 25*(9), 1049-1079.

Overdesvest, C., Orr, C. H., & Stepenuck, K. (2004). Volunteer stream monitoring and local participation in natural resources issues. *Research in Human Ecology, 11*(2), 177-185.

Parchmann, I., Grasel, C., Baer, A., Nentwig, P., Demuth, R., & Ralle, B. (2006). “Chemie im Kontext”: A symbiotic implementation of a context-based teaching and learning approach, *International Journal of Science Education, 28*(9), 1041-1062.

Pattie, C., & Seyd, P. (2003). Citizenship and civic engagement: Attitudes and behaviour in Britain. *Political Studies, 51*, 443–468.

Paulsen, R. (1991). Education, social class, and participation in collective action. *Sociology of Education, 64*, 96-110.

PCN (2018). *National curriculum parameters secondary education*. Brasília: Ministry of Education. Retrieved online: http://portal.mec.gov.br/seb/arquivos/pdf/pcning.pdf

Pelch, M.A., & McConnell, D.A. (2017). How does adding an emphasis on socioscientific issues influence student attitudes about science, its relevance, and their interpretations of sustainability? *Journal of Geoscience Education, 65*(2), 203-214.

Penuel, W. R. & Fishman, B. J. (2012). Large-scale science education intervention research we can use. *Journal of Research in Science Teaching, 49*(3), 281-304.

Pew Research Center (2017). *U.S. trails most developed countries in voter turnout*. Retrieved from http://www.pewresearch.org/fact-tank/2017/05/15/u-s-voter-turnout-trails-most-developed-countries/.
Reis, S. M. & Park, S. (2001). Gender differences in high-achieving students in math and science. *Journal for the Education of the Gifted, 25*(1), 52-73.

Renninger, K. A., & Hidi, S. (2016). *The power of interest for motivation and learning*. New York, NY: Routledge.

Roth, W.-M., & Lee, S. (2002). Scientific literacy as collective praxis. *Public Understanding of Science, 11*(1), 33–56.

Rudolph, J. L. (2014). Dewey’s “science as method” a century later: Reviving science education for civic ends. *American Educational Research Journal, 15*(6), 1056-1083.

Rudolph, J. L. (2020). The lost moral purpose of science education. *Science Education, 104*(5), 895-906.

Rudolph, J. L., & Horibe, S. (2016). What do we mean by science education for civic engagement?. *Journal of Research In Science Teaching, 53*(6), 805-820.

Rutherford, F. J., & Ahlgren, A. (1989). Science for all Americans. Washington, DC: AAAS.

Sadler, T. D., Romine, W. L., Stuart, P. E., & Merle-Johnson, D. (2013). Game-based curricula in biology classes: Differential effects among varying academic levels. *Journal of Research in Science Teaching, 50*(4), 479-499.

Schiefele, U., Krapp, A., & Winteler, A. (1992). Interest as a predictor of academic achievement: A meta-analysis of research. In K. A. Renninger, S. Hidi, & A. Krapp (Eds.), *The role of interest in learning and development* (pp. 183-212). Hillsdale, NJ: Erlbaum.

Schiefele, U. (2009). Situational and individual interest. In K. R. Wentzel & A. Wigfield (Eds.), *Handbook of motivation at school* (pp. 197-222). New York, NY: Routledge.

Schindel Dimick, A. (2016). Exploring the Potential and Complexity of a Critical Pedagogy of Place in Urban Science Education. *Science Education, 100*(5).
Schudson, M. (1999). Good Citizens and Bad History: Today’s Political Ideals in Historical Perspective. Paper presented at a Conference on the Transformation of Civic Life. Middle Tennessee State University, November 12-13, 1999.

Sellmann, D., & Bogner, F. X. (2013). Climate change education: quantitatively assessing the impact of a botanical garden as an informal learning environment. Environmental Education Research, 19(4), 415-429.

Senecah, S. (2004). The trinity of voices: The role of practical theory in planning and evaluating the effectiveness of environmental participatory processes. In S.P. Depoe, J.W. Delicath, & M-F. Elsenbeer (Eds.), Communication and public participation in environmental decision making (pp. 13-33). Albany, NY: State University of New York Press.

Sevigny, C. (2021). Sustainable Missoula: The next generation of environmental problem solvers. Missoula Current (March 26, 2021). Available online at: https://missoulacurrent.com/outdoors/2021/03/environmental-problem-solvers/

Sherrod, L. R., Torney-Purta, J., & Flanagan, C. A. (2010). Handbook of research on civic engagement in youth. Hoboken, NJ: Wiley.

Silvia, P. J. (2006). Exploring the psychology of interest. Oxford, UK: Oxford University Press.

Solomon, J., & Aikenhead, G. (1994). STS education: International perspectives in reform. New York: Teachers’ College Press.

Somerville, P. (2020). A critique of climate change mitigation policy. Policy & politics 48(2), 355-378.

Stapp, W.B., et al. (1969). The concept of environmental education. Journal of Environmental Education, 1(1), 30-1.

Stroupe, K. S., & Sabato, L. J. (2004). Politics: The missing link of responsible civic education.
Circle Working Paper 18. Available at www.civicyouth.org

Tirri, K., Tolppanen, S., Aksela, M., & Kuusisto, E. (2012). A cross-cultural study of gifted students' scientific, societal, and moral questions concerning science. *Education Research International*.

Torney-Purta, J., Cabrera, J. C., Roohr, K. C., Liu, O. L., & Rios, J. A. (2015). Assessing civic competency and engagement in higher education: Research background, frameworks, and direction for next–generation assessment. Princeton, NJ: Educational Testing Service.

Trumbull, D. J., Bonney, R., Bascom, D., & Cabral, A. (2000). Thinking scientifically during participation in a citizen-science project. *Science Education, 84*(2), 265-275.

Tsai, C., -Y. (2019). The effect of online argumentation of socioscientific issues on students' scientific competencies and sustainability attitudes. *Computers & Education, 116*, 14-27.

UNESCO. (1978). Intergovernmental conference on environmental education. Available online at: http://unesdoc.unesco.org/images/0003/000327/032763eo.pdf

UNESCO. (2012). Education for sustainable development. Available online at http://www.unesco.org/new/en/education/networks/global-networks/aspnet/study-areas/education-for-sustainable-development/

UNESCO. (2021). Sustainable development goals: Target 4.7. Available online at http://tbg.uis.unesco.org/wp-content/uploads/sites/4/2020/09/Metadata-4.7.4.pdf

United States General Services Administration (2020). About CitizenScience.gov. Available online at https://www.citizenscience.gov/about/

Vissers, S., & Stolle, D. (2014). Spill-over effects between Facebook and on/offline political participation?: Evidence from a two-wave panel study. *Journal of Information Technology & Politics, 11*(3), 259-175.
Wallace, D. E. & Bodzin, A. M. (2017). Developing scientific citizenship identity using mobile learning and authentic practice. *Electronic Journal of Science Education, 21*(6), 46-71.

Warmbrod, L., Trotochaud, M., & Connell, N. (2019). The scientist citizen and the citizen scientist: Blurring the lines. *ILAR Journal, 60*(1), 5–8.

Wells, S. D. & Dudash, E. A. (2007). Wha’d’ya know?: Examining young voters’ political information and efficacy in the 2004 election. *American Behavioral Scientist, 50*(9), 1280-1289.

Westheimer, J. & Kahne, J. (2004). What kind of citizen? The politics of educating for democracy. *American Educational Research Journal, 41*(2), 237-269.

Wilson, E. O. (1999). *Consilience: The unity of knowledge*. Vintage Books.

Wu, Y.-T., & Tsai, C.-C. (2007). High school students’ informal reasoning on a socioscientific issue: Qualitative and quantitative analyses. *International Journal of Science Education, 29*(9), 1163–1187.

Youniss, J., Bales, S., Christmas-Best, V., Diversi, M., McLaughlin, M., & Silbereisen, R. (2002). Youth civic engagement in the twenty-first century. *Journal of Research on Adolescence, 12*(1), 121-148.

Zeidler, D.L. (2003). *The role of moral reasoning on socioscientific issues and discourse in science education*. The Netherlands: Kluwer.

Zeidler, D., Sadler, T., Simmons, M., & Howes, E. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education, 89*(3), 357-377.