A Vision for University Biology Education for Non-science Majors

Cara Gormally[†]* and Austin Heil[‡]
[†]School of Science, Technology, Accessibility, Mathematics, and Public Health, Gallaudet University, 800 Florida Avenue NE, Washington, DC 20002; [‡]Marine Extension and Georgia Sea Grant, University of Georgia, Savannah, GA 31411

ABSTRACT
As college science educators, we must prepare *all* future college graduates to be engaged, science-literate citizens. Yet data suggest that most college biology classes as currently taught do little to make science truly useful for students' lives and provide few opportunities for students to practice skills needed to be key decision makers in their communities. This is especially important for our non-science majors, as they represent the vast majority (82%) of college students. In this essay, we identify three critical aspects of useful college science education to prepare science literate non-science majors: prioritize local socioscientific issues; highlight communal opportunities in science that impact students' communities; and provide students with opportunities to practice skills necessary to engage with science beyond the classroom.

INTRODUCTION: A CALL FOR ACTION
Complex scientific issues such as the COVID-19 pandemic and climate change affect our day-to-day lives both individually and collectively. We face challenging decisions related to science that have personal and societal implications, for example, whether to vaccinate and whether to support carbon offset credits. And our ability to respond is compromised by misinformation (d'I Treen *et al.*, 2019; Puri *et al.*, 2020; Suarez-Lledo and Alvarez-Galvez, 2021; West and Bergstrom, 2021; Southwell *et al.*, 2022). For example, college graduates represent 35% of all Americans (U.S. Census Bureau, 2019) and nearly one in four of these graduates believed conspiracy theories that COVID-19 was planned (Schaeffer, 2020). Improving science literacy among college students is key to solving this problem of misinformation about climate change, COVID-19, and other socioscientific issues we face—and a fundamental aim of science education. As college science educators, we must better equip *all* students to make sound decisions in the face of misinformation.

More than eight out of 10 college students are not science majors (National Center for Education Statistics [NCES], 2013, 2021). These students are our future leaders, including our future lawyers, business owners, and politicians. However, as college educators and researchers, we tend to overlook this huge population of students who need science in lieu of preparing science, technology, engineering, and mathematics (STEM) majors to be the next generation of STEM professionals (Coley and Tanner, 2015). In reality, only five in 100 students will become our doctors, scientists, and engineers (Sargent, 2017). In this essay, we present an evidence-based vision for non-major biology courses focused on scientific literacy for the vast majority of college-educated citizens—our non-science majors. Our positionality as instructors at 4-year institutions of higher education informs our standpoint in this essay.

DEFINING SCIENCE LITERACY
There are many definitions of science literacy in science education, and how we define it impacts how we measure it. Historically, science literacy has been defined in terms of content knowledge (Miller, 1998; Allum *et al.*, 2008). Unsurprisingly, the adoption

Sehoya Cotner, *Monitoring Editor*
Submitted Dec 16, 2021; Revised Jul 26, 2022; Accepted Aug 4, 2022
CBE Life Sci Educ December 1, 2022 21:es5
DOI:10.1187/cbe.21-12-0338
*Address correspondence to: Cara Gormally (cara.gormally@gallaudet.edu).

of content-focused definitions led to assessments of science literacy that focused on the general public's ability to regurgitate scientific facts and demonstrate an understanding of scientific principles/knowledge (Goodstein, 1992; Hazen, 2002; Johnson and Pigliucci, 2004; Allum *et al.*, 2008; Miller, 2010, 2016). Estimates of scientific literacy varied using these content-focused assessments, but consistently pointed to high rates of science illiteracy across different populations (Allum *et al.*, 2008; Miller 2004, 2016).

More recently, science literacy has been defined as skills needed to make science knowledge useful and usable in everyday life (Gormally *et al.*, 2012). To the best of our knowledge, there is only one freely available measure of scientific literacy that directly evaluates student skill development related to the capacity for scientifically informed action: the Test of Scientific Literacy Skills (TOSLS; Gormally *et al.*, 2012; for a review of instruments that measure scientific reasoning, please see Opitz *et al.*, 2017). There are no equivalent studies to the content-focused assessments mentioned earlier that investigate science literacy in terms of skills for the general public, as estimates of science literacy using TOSLS are often limited to pedagogical, curricular, and programmatic contexts (Gormally *et al.*, 2012; Waldo, 2014; Shaffer *et al.*, 2019). However, these assessments pointed to lower scientific literacy skills for non-science majors that improved with innovative pedagogical and curricular efforts.

While a variety of definitions and subsequent assessments of science literacy exist, in this essay we adopt the definition that scientific literacy is the capacity to take scientifically informed action to make evidence-based decisions in everyday life (American Association for the Advancement of Science [AAAS], 1990, 1993, 2011; Bybee, 1993; National Research Council [NRC], 1996; Maienschein, 1998; Millar *et al.*, 1998; DeBoer, 2000; Organisation for Economic Co-operation and Development, 2003). Based on this definition, we assert that our students must be able to use evidence to evaluate arguments and claims in the media and, ultimately, use scientific information to make a personally relevant decision (i.e., such as whether to get a COVID-19 vaccination or buy cereal containing genetically modified food products). Simply put, science must be useful for students (Feinstein, 2011). Thus, we argue science literacy should be assessed in terms of skills (Gormally *et al.*, 2012).

WHO ARE OUR NON-SCIENCE MAJORS?

NCES (2013) estimates that ~85% of the 1.8 million students graduating from college annually in the United States are not science majors. Non-science majors are our future leaders, activists, teachers, lawyers, artists, counselors, voters, and parents. They must be ready to engage in discussions about important scientific issues. As individuals and as a society, they will need to evaluate climate change threats, react to genetically modified food crops, weigh health choices, and much more.

Non-science majors and science majors differ in several ways (Table 1). A small study comparing non-biology ($N = 30$) and biology majors ($N = 25$) revealed differences existing before college, as students' ACT scores differed significantly (Hebert and Cotner, 2019). Fewer non-biology majors than biology majors reported taking advanced high school science classes (Hebert and Cotner, 2019). Interestingly, the population of non-biology majors was more diverse—in terms of incoming knowledge, perceptions, backgrounds, and skills—than the biology majors' population (Cotner *et al.*, 2017).

Non-biology majors and biology majors demonstrate affective differences toward science (Knight and Smith, 2010; Cotner *et al.*, 2017; Hebert and Cotner, 2019). Perhaps unsurprisingly, non-biology majors were less likely to describe themselves as "a science person," were less confident in their ability to "do" science (e.g., pose questions, analyze results, and draw conclusions based on data), and had less interest in science than biology majors (Hebert and Cotner, 2019). Non-biology majors also reported different perceptions of science and the usefulness of science (Hebert and Cotner, 2019). While Cotner *et al.* (2017) reported that non-biology majors are more likely to hold misconceptions about the nature of science, Miller *et al.* (2010) reported that both non-science and science majors held a mix of naïve, transitional, and moderately informed views about the nature of science. Generally, however, both populations viewed science as relevant and important, similar to findings from studies by Miller (2004) and Allum *et al.* (2008) investigating the general public's attitudes toward science. Earlier work by Cotner *et al.* (2017) reported non-biology majors were less likely to see science as personally relevant.

Multiple studies suggest that instructors should focus on improving non–science majors' affective traits, such as interest, motivation, and attitudes toward science. For example, while non-biology majors and biology majors do not differ significantly in their abilities to "do" science, non-biology majors report a confidence gap (Hebert and Cotner, 2019). Likewise, Glynn *et al.* (2011) reported that biology majors scored higher on every motivation component than non-biology majors. Non-science majors reported less interest in genetics, found genetics less relevant to their future careers, and were less motivated to study (Knight and Smith, 2010). The authors also reported performance differences. Knight and Smith (2010) recommended addressing this disparity by focusing on changing student attitudes rather than content. Instructors may do well to connect concepts to real-world applications, so that non-science majors can connect new ideas with their mental models to form a "bigger picture." Positive attitudes toward science must be encouraged and supported among non-science majors. Poorer attitudes toward science (Allum *et al.*, 2008) are related to poorer outcomes in science—including decreased science literacy (Cook and Mulvihill, 2008).

HOW IS UNDERGRADUATE BIOLOGY CURRENTLY TAUGHT TO OUR NON-SCIENCE MAJORS?

Science courses are often a general education requirement for non-science majors. General education, a shared core curriculum that can take many forms, provides broad exposure to multiple disciplines, including science, with opportunities for students to develop critical civic competencies (Association of American Colleges and Universities, 2002). General education is the place where students come to understand that everything we teach relates to their lives ("General Education, Finally Defined," 2007) or *should* relate to their lives. While *Vision and Change* (AAAS, 2011) guides learning for biology majors, at the time of writing this article, there are no national standards or recommendations for learning objectives for biology for non-science majors.

TABLE 1. Summary of characteristic differences between undergraduate science majors and non-science majors

Source	Characteristic	Nonmajors	Majors
Hebert and Cotner (2019)	ACT scores	⇓ Scores	⇑ Scores
Hebert and Cotner (2019)	No. of advanced high school courses	⇓ Courses	⇑ Courses
Cotner *et al.* (2017)	Diversity of knowledge, perception, backgrounds, and skills	⇑ Diverse	⇓ Diverse
Hebert and Cotner (2019)	Describe themselves as a "science person"	⇓ Likely	⇑ Likely
Hebert and Cotner (2019)	Confidence in ability to "do" science	⇑ Confidence	⇓ Confidence
Hebert and Cotner (2019)	Interest in science	⇓ Interest	⇑ Interest
Miller (2004); Allum *et al.* (2008); Cotner *et al.* (2017)	Find science personally relevant	⇓ Relevant	⇑ Relevant
Knight and Smith (2010); Glynn *et al.* (2011)	Motivation to do science	⇓ Motivation	⇑ Motivation
Miller *et al.* (2010); Cotner *et al.* (2017)	Misconceptions about nature of science	⇑ Misconceptions	⇓ Misconceptions
Hebert and Cotner (2019)	Ability to "do" science	= Ability	= Ability

Faculty teaching non-science majors express support for teaching scientific literacy skills, especially the nature of science, research design, evaluating source validity, and evaluating the use and misuse of scientific information (Gormally *et al.*, 2012). In fact, a large majority of faculty surveyed (≥58.7%, $N = 188$) reported that they teach these scientific literacy skills (with the exception of teaching understanding and interpreting basic statistics, which only 44.9% of faculty report teaching; Gormally *et al.*, 2012). However, these faculty self-report data conflict with a more recent analysis of learning objectives ($N = 872$) collected from 38 faculty nationwide and from three best-selling textbooks for non-science majors ($N = 1390$; Heil *et al.*, in press). Few learning objectives (11.5%) from instructors or textbooks focused on science literacy skills useful for making science-informed decisions (Heil *et al.*, in press). And 80% of learning objectives for non-science majors could be classified as requiring only low levels of thinking as measured by Bloom's taxonomy (Heil *et al.*, in press). Scientific literacy is often equated with specific content knowledge: When surveyed about skills required for scientific literacy, faculty responses categorized as specific content knowledge accounted for more responses than any one scientific literacy skill described (Gormally *et al.*, 2012).

Science courses as currently taught do little to promote socioscientific decision making (Feinstein, 2011). When it comes to class time, faculty tend to cover vast amounts of fundamental biological content but fail to see the importance of making these concepts relevant to students' lives. For example, faculty teaching human genetics courses for non-science majors ($N = 63$) rated genetics and society concepts (the application of genetics to human health, ethical implication of genetic testing, etc.) of least importance among all survey concepts (Bowling *et al.*, 2007). Furthermore, faculty failed to take advantage of the vast amount of genetics in the popular media, reporting that they spent only 7% of class time on average on "genetics in the news" (Bowling *et al.*, 2007). Other studies have reported similar faculty disregard of socioscientific issues for non-science major courses. For example, genetics instructors preferred a curriculum with a vast coverage of content to one that emphasized concepts that were most relevant to students' lives (Haffie *et al.*, 2000; Hott *et al.*, 2002). Most science courses focus on imparting practices and knowledge rather than considering the political, economic, or social dimensions of issues and how they relate to students' lives and experiences (Bowers, 2002; Fredeen, 2012).

Unsurprisingly, given the focus on content over skills or relevance, science instruction has not been shown to directly impact the decisions people make related to science and society (Mulkay, 1997; Sadler, 2004; Feinstein, 2011; Crowell and Schunn 2014; Allum *et al.*, 2018) or concerns they have about socioscientific issues (Kahan *et al.*, 2012). Students do not connect "science as a way of knowing" with the decisions they face in their daily lives (Kuhn, 1993; Walker *et al.*, 2002; Rowe *et al.*, 2015) or as part of their personal knowledge (Sadler, 2004). This suggests that we, as college science faculty, are not making scientific knowledge relevant to students' lives. Our current approach to science education not only fails to foster true scientific literacy, but also alienates many students from science (Seymour and Hewitt, 1997; Ede, 2000; Johnson, 2007). Ultimately, this jeopardizes America's global competitiveness (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2007). These findings indicate a need to revisit the goals of instruction for our non-science majors—the vast majority of college students.

WHAT CRITICAL ASPECTS SHOULD BE INCLUDED IN OUR COURSES FOR NON-SCIENCE MAJORS?

Studies from the past decade offer little evidence that the prevailing strategies in science education have an impact on how individuals use science in their daily lives. Feinstein (2011) argues: What need is there for scientific literacy, if we insist on its usefulness without demonstrating how or why it is useful for our citizens? How, then, can we make science education "useful" for all college students? Feinstein (2011) proposes that a "truly useful version of science literacy must be connected to the real uses of science in daily life (p. 168)." Focusing on "making science useful" as our overarching goal, we offer three recommendations for our fellow faculty teaching non-science major courses moving forward: 1) use local socioscientific issues as a lens for learning; 2) highlight communal opportunities that impact students' communities; and 3) practice skills necessary for students to engage with science beyond the classroom. Each recommendation is explored in depth in the following sections.

Use Local Socioscientific Issues as a Lens for Learning

Recognizing what we know about adults' engagement with science beyond the classroom can help us better prepare students to make use of science in their everyday lives. We live in a science-rich world situated in the activities of everyday life. Science learning encompasses an increasing amount of time in individuals' lives beyond the classroom (Falk *et al.*, 2007). This free-choice science learning is driven by individuals' desire to know, intrinsic motivation rather than extrinsic motivation (e.g., grades). Beyond the classroom, adults do not necessarily engage in science-related activities simply to learn about science. Instead, people are motivated by social experiences and entertainment (American Academy of Arts and Sciences, 2019a), as well as current events about socioscientific issues in the media (Falk *et al.*, 2007).

Consequently, building on what we know about how adult learners interact with science beyond the classroom suggests that contextualizing learning through socioscientific issues—especially local issues—may help students build meaningful connections to science (Allum *et al.*, 2008; Funk *et al.*, 2015). Students enrolled in a laboratory curriculum based on socioscientific issues had increased motivation to engage in laboratory activities compared to students enrolled in a control laboratory course (Hewitt *et al.*, 2019). Additionally, the socioscientific issues curriculum appeared to have a buffering effect on student motivation throughout the semester, as typically observed declines in motivation were not observed (Hewitt *et al.*, 2019). Qualitative data suggest that students' increased motivation was the result of enhanced feelings of relatedness, which could be important for student success and persistence (Hewitt *et al.*, 2019). However, it is important to note that the socioscientific issues lab and control lab curricula also differed in that the former used an inquiry-based approach, while the latter used a traditional cookbook approach (Hewitt *et al.*, 2019).

Moreover, teaching biology via the lens of socioscientific issues may reduce the stark differences in opinions about socioscientific issues between scientists and the general public. Scientists and the public differ in their opinions about issues such as the safety of genetically modified food; use of animals in research; human evolution; human activity as a major cause of climate change; and growth of the world population becoming a major issue (Funk *et al.*, 2015). This difference suggests non-science major courses should use an issues-based approach as a way for our students to learn science to make informed decisions about these important socioscientific issues.

Highlight Communal Opportunities in Science That Impact Students' Communities

Curricular interventions can also reduce differences in affective traits between non-science majors and science majors (Knight and Smith, 2010; Hebert and Cotner, 2019). These affective traits include seeing oneself as a science person (Gormally and Marchut, 2017; Hebert and Cotner, 2019) and seeing science as relevant to one's life (Cotner *et al.*, 2017). Seeing oneself as a science person requires seeing science as containing a possible future self. For many students, especially those historically underserved in science, this means seeing opportunities to achieve communal career goals, centered around working with and helping people (Allen *et al.*, 2015; Brown *et al.*, 2015; Gormally and Marchut, 2017; Gormally and Inghram, 2021). This means careers must offer opportunities to develop interpersonal connections and to help other people or society (Allen *et al.*, 2015; Brown *et al.*, 2015).

Science *can* be a vehicle for creating positive change in our communities. For example, interview studies illuminated how women of color with communal science identities redefined for themselves what it meant to be in science and whose recognition was important to them (Carlone and Johnson, 2007). However, undergraduate biology education does not often contextualize curricula around the idea of science as a vehicle for communal good.

Instead, the predominant stereotypes of nerdy scientists working in isolation continue to negatively impact students' interest in science (Brown *et al.*, 2015; Schinske *et al.*, 2015). These stereotypes may contribute to students' science identity. Seeing oneself as a "science person" may be impossible if one holds misperceptions about scientists (Hazari *et al.*, 2013). Unfortunately, these stereotypes disproportionately affect students from groups underserved in science, including women, people of color, first-generation college students, and students of low socioeconomic status, who tend to value career goals focused on helping and working with people to give back to one's community. As a result, these stereotypes preclude students' interest in science learning, because science is not perceived as affording these communal career goals (Diekman *et al.*, 2010; Allen *et al.*, 2015; Brown *et al.*, 2015).

There are several ways to center communal opportunities in science education. Service learning is one approach. In fact, even the mention of a service-learning project in a course description for an engineering class increased students' beliefs that the course fulfills communal goals (Belanger *et al.*, 2017). Likewise, emphasizing the "why" to engage in science activities helps students to identify communal opportunities in science. For example, when an opportunity to help the broader community or society was present, students reported high levels of interest in pursuing STEM (Steinberg and Diekman, 2018). By highlighting communal opportunities in STEM, we, as college science educators, may disrupt common stereotypes, thus more effectively engaging students in science learning so that they are motivated to become scientifically literate.

Faculty can also directly address stereotypes about scientists and science through curricular activities. Diversifying images of computer scientists and engineers increased interest in computer science and engineering (Cheryan *et al.*, 2015). Faculty may consider who they highlight as "scientist representatives" so that all students feel seen and valued and develop a sense of belonging—and thus are motivated to engage in science learning. For example, faculty might use resources from Scientist Spotlights (Schinske *et al.*, 2016) or Project Biodiversify to combat stereotype threat. To address these stereotypes in computer science and engineering activities, researchers highlighted communal opportunities with direct connections to real-life scenarios. For example, in civil engineering curricular activities about building structures for water transportation and purification and bridges, educators highlighted how each project would improve community members' lives (Colvin *et al.*, 2013). Educators also prompted students to reflect on communal considerations of each project, for example, environmental impacts of the structure and safety, while recognizing the conflicting interests that might come into play in designing such a project (Colvin *et al.*, 2013).

Practice Skills Necessary to Engage with Science beyond the Classroom

All college students must practice scientific literacy skills to engage with science beyond the classroom. This means faculty must consider how students engage with science beyond the classroom. The Internet is a primary source of scientific information (Falk *et al.*, 2007; National Science Foundation [NSF], 2014) for 40 million Americans (20% of all Internet users in the United States), and 87% of users report having searched online about science at least once (Horrigan, 2006). Both youth and adults gather much of their scientific information from online resources like WebMD, social media, and Wikipedia (Anderson *et al.*, 2010). Social media is increasingly important as a source of scientific information, with 33% of Americans saying this is an important way they get science news (Funk *et al.*, 2017). Adults who are relatively more frequent users of print and Internet information sources are more likely to be scientifically literate (Miller, 2010). This relationship suggests that learning how to identify high-quality sources of information is an important skill for developing scientific literacy.

While Internet and social media access increase individuals' access to scientific information, these platforms can also foster the spread of misinformation (Burki, 2019; Smith and Seitz, 2019). An analysis of conversations on social media platforms indicated that members discussed more about the politics of vaccine use than the science, resulting in a spread of misinformation (Orr and Basam-Tsabari, 2018). The spread of scientific misinformation can be attributed to two conflicting reasons: Individuals uncritically accept most scientific information, and they reject information that fits outside their worldview (Sharon and Basam-Tsabari, 2020).

Moreover, the research is quite clear that individuals do not use scientific knowledge to make everyday decisions around science-related issues; instead, adults tend to identify and judge appropriate scientific expertise (Hilton *et al.*, 2007; Ajzen *et al.*, 2011; Kahan *et al.*, 2012; Feinstein, 2014; Crowell and Schunn, 2016; Shauli and Baram-Tsabari, 2019). Consequently, creating opportunities for students to practice identifying and judging appropriate scientific expertise is critical, as this skill is useful for adults (Feinstein, 2014).

While Internet use is ubiquitous, college students struggle to evaluate the relevance and reliability of information found via Web searches (MaKinster *et al.*, 2002; Brand-Gruwel *et al.*, 2009). In fact, very few Internet users check the source and date of the information they find. Wineberg and McGrew (2017) reported that PhD historians and college students were unable to evaluate credibility of websites and even preferred sources that promoted misinformation. To support our students' development of information literacy skills, faculty should incorporate opportunities to evaluate students' use of Internet searches to find scientific information (Britt and Aglinskas, 2002; Walraven *et al.*, 2009). Evaluating credibility becomes more challenging with little knowledge of the topic (Braten *et al.*, 2011). Faculty can challenge students to move beyond reliance on surface markers, for example, dates of posting and the presence of details and percentages as evidence of accuracy (Brem *et al.*, 2001). These are critical skills for our students to be capable of critiquing the quality of sources of scientific information, which is a key step in analyzing scientific arguments and evidence.

Looking to student challenges related to scientific literacy skills is also fruitful for curricular development (Gormally *et al.*, 2012). The ability to recognize and analyze methods of inquiry that lead to scientific knowledge is at the heart of many scientific literacy skills (Gormally *et al.*, 2012). Students must be able to critique scientific experiments, data, and results to make decisions about the ill-structured problems in their everyday lives. Essentially, students must be capable of analyzing the strength of evidenced-based arguments. However, students have trouble developing claims backed by evidence and reasoning (Speth *et al.*, 2010), as well as linking the claims to specific evidence (Cho and Jonassen, 2002). Asking students to evaluate media reports of scientific information and use scientific evidence to make decisions are ways to practice evaluating scientific arguments (Brickman *et al.*, 2012; Rowe *et al.*, 2015). Practicing evaluating arguments helps students to identify sensationalism and oversimplification of study findings often found in media reports (Tankard and Ryan, 1974; Pellechia, 1997; Kua *et al.*, 2004), as well as to recognize that media reports often omit study limitations (Woloshin and Schwartz, 2006). Additionally, college students were found to demonstrate stronger, more sophisticated rationales around decisions regarding socioscientific issues when given opportunities to practice skills (Dauer and Forbes, 2016).

It is critical to note that scientifically informed action is driven by more than just scientific literacy alone (Crowell and Schunn, 2014). Individuals' feelings of personal responsibility to the issue also matter, as well as the specific context, whether one transfers behaviors across contexts, and whether the proposed action or behavior is deemed to be practical (Crowell and Schunn, 2014). And attitudes about scientific advances and innovations are more likely to vary with individuals' social backgrounds, identities, mental models, and information sources than with knowledge (Allum *et al.*, 2008).

PREPARING SCIENCE LITERATE NON-SCIENCE MAJORS WITH USEFUL SCIENCE EDUCATION

We argue that future non-science major courses should integrate local socioscientific issues, highlight communal opportunities in science that impact students' communities, and provide students with opportunities to practice skills necessary to engage with science beyond the classroom to promote science literacy. Recent research reports that courses like this are still the exception, not the norm (Heil *et al.*, 2021; A. Heil, C. Gormally, M. Brickman, unpublished data). Perhaps most importantly, effective teaching of non-science majors is dependent on the interest and commitment of individual faculty. As a result, progress depends on demanding that effective teaching of non-science majors is institutionalized and recognized as a critical professional standard in science education. Our work points to a need for policy to guide effective teaching for science literacy, such as an expansion of *Vision and Change* through the operationalization of learning objectives for non–science majors' courses (M. Brickman and C. Gormally, unpublished data) and resources such as BioSkills (Clemmons *et al.*, 2020). The development of *Vision and Change*–informed learning objectives for non–science majors' courses may be useful for all faculty, and especially faculty working within institutional structures that strictly enforce content coverage due to articulation of courses and accreditation purposes (M. Brickman and C. Gormally, unpublished data). Progress is otherwise doomed if it is dependent on individual faculty heroes.

CONCLUSION

Currently, we are failing to prepare our students effectively to meet the AAAS (2011) charge to educate our citizens "for civic engagement and responsibility." STEM majors represent only a fraction of college students. As faculty, we must consider the specific needs of college students who are not STEM majors. We face growing numbers of socioscientific issues: pandemics, vaccine resistance, climate change denial, novel technologies, and advances in genomic medicine. As science educators, we have an urgent obligation to address this pressing problem, so that our non-science majors will become avid consumers of science—using science information to make everyday decisions and, importantly, contributing to larger societal conversations. DeBoer (2000, p. 598) notes:

> Ultimately what we want is a public that finds science interesting and important, who can apply science to their own lives, and who can take part in the conversations regarding science that take place in society. Not everyone will develop the same knowledge and skill but feeling that one can continue to learn and participate are key elements to life in a democratic society.

How we teach undergraduate biology for non-science majors matters. As currently taught, most courses for non-science majors prioritize content coverage rather than making these concepts relevant to students' lives (Haffie *et al.*, 2000; Hott *et al.*, 2002; Bowling *et al.*, 2007; Fredeen, 2012). Instead, faculty must holistically rethink course structure to prioritize students' development of science literacy. One current challenge faculty face is the lack of clearly articulated direction for what non-science majors should learn, in terms of concepts and skills. To address this barrier, operationalizing policy documents such *Vision and Change* into articulated learning objectives describing key concepts and skills students should learn is an important next step currently underway (M. Brickman and C. Gormally, unpublished data). A validated set of learning objectives offers faculty a clear way forward. Evidence-based articulated learning objectives may help reduce the burden for change from individual faculty members, instead supporting systemic intra- and cross-institutional change. At the intra-institutional level, articulated learning objectives describing concepts and skills critical for science literacy would support systemic change so that course sections for non-science majors are aligned.

At the cross-institutional level, adoption of common learning objectives could better support the transition from 2-year to 4-year institutions. Further, support for faculty professional development and curricular development is important for addressing barriers that might affect course reform. Professional development must offer faculty more support than one-time workshop attendance (Dancy and Henderson, 2010; Singer *et al.*, 2012). Organizations such as Science Education for New Civic Engagements and Responsibilities and the Network of STEM Education Centers, as well as research coordination networks, may offer opportunities for deep engagement in faculty learning communities.

Faculty must re-envision courses so that all students have opportunities to grapple with local socioscientific issues that are relevant and meaningful to their lives. And faculty must highlight how biology affords altruistic, communal opportunities in order to engage students who continue to be marginalized in STEM. College students must be equipped with the skills necessary to be scientifically literate, to be the leaders we need, to make decisions in their personal lives, and to contribute to the ever-growing number of decisions we face as a society. We know that exposure to a college science course is a strong predictor of scientific literacy (Miller, 2016). Imagine what we could accomplish collectively if we could raise the bar for numbers of students achieving actionable scientific literacy.

ACKNOWLEDGMENTS

We thank Peggy Brickman and Scott Freeman for their thoughtful early reads of our work.

REFERENCES

Ajzen, I., Joyce, N., Sheikh, S., & Cote, N. G. (2011). Knowledge and the prediction of behavior: The role of information accuracy in the theory of planned behavior. *Basic and Applied Social Psychology*, *33*(2), 101–117.

Allen, J. M., Muragishi, G. A., Smith, J. L., Thoman, D. B., & Brown, E. R. (2015). To grab and to hold: Cultivating communal goals to overcome cultural and structural barriers in first-generation college students' science interest. *Translational Issues in Psychological Science*, *1*(4), 331.

Allum, N., Besley, J., Gomez, L., & Brunton-Smith, I. (2018). Disparities in science literacy. *Science*, *360*(6391), 861–862.

Allum, N., Sturgis, P., Tabourazi, D., & Brunton-Smith, I. (2008). Science knowledge and attitudes across cultures: A meta-analysis. *Public Understanding of Science*, *17*(1), 35–54.

American Academy of Arts and Sciences. (2019). *Encountering science in America*. Cambridge, MA.

American Association for the Advancement of Science (AAAS). (1990). *Science for all Americans.* New York: Oxford University Press.

AAAS. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

AAAS. (2011). *Vision and change: A call to action*. Washington, DC. Retrieved December 15, 2021, from https://visionandchange.org/about -vc-a-call -to-action-2011

Anderson, A. A., Brossard, D., & Scheufele, D. A. (2010). The changing information environment for nanotechnology: Online audiences and content. *Journal of Nanoparticle Research*, *12*(4), 1083–1094.

Association of American Colleges and Universities. (2002). *Greater expectations: A new vision for learning as a nation goes to college*. Washington, DC.

Belanger, A. L., Diekman, A. B., & Steinberg, M. (2017). Leveraging communal experiences in the curriculum: Increasing interest in pursuing engineering by changing stereotypic expectations. *Journal of Applied Social Psychology*, *47*(6), 305–319.

Bowers, C. A. (2002). Toward an eco-justice pedagogy. *Environmental Education Research*, *8*(1), 21–34.

Bowling, B. V., Huether, C. A., & Wagner, J. A. (2007). Characterization of human genetics courses for nonbiology majors in US colleges and universities. *CBE—Life Sciences Education*, *6*(3), 224–232.

Brand-Gruwel, S., Wopereis, I., & Walraven, A. (2009). A descriptive model of information problem solving while using Internet. *Computers & Education*, *53*(4), 1207–1217.

Bråten, I., Strømsø, H. I., & Salmerón, L. (2011). Trust and mistrust when students read multiple information sources about climate change. *Learning and Instruction*, *21*(2), 180–192.

Brem, S. K., Russell, J., & Weems, L. (2001). Science on the Web: Student evaluations of scientific arguments. *Discourse Processes*, *32*(2–3), 191–213.

Brickman, P., Gormally, C., Francom, G., Jardeleza, S. E., Schutte, V. G., Jordan, C., & Kanizay, L. (2012). Media-savvy scientific literacy: Developing critical evaluation skills by investigating scientific claims. *American Biology Teacher*, *74*(6), 374–379.

Britt, M. A., & Aglinskas, C. (2002). Improving students' ability to identify and use source information. *Cognition and Instruction*, *20*(4), 485–522.

Brown, E. R., Thoman, D. B., Smith, J. L., & Diekman, A. B. (2015). Closing the communal gap: The importance of communal affordances in science career motivation. *Journal of Applied Social Psychology*, *45*(12), 662–673.

Burki, T. (2019). Vaccine misinformation and social media. *Lancet Digital Health*, *1*(6), 258–259.

Bybee, R. W. (1993). *Reforming science education. Social perspectives & personal reflections*. New York, NY: Teachers College, Columbia University.

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching*, *44*(8), 1187–1218.

Cheryan, S., Master, A., & Meltzoff, A. N. (2015). Cultural stereotypes as gatekeepers: Increasing girls' interest in computer science and engineering by diversifying stereotypes. *Frontiers in Psychology*, *6*, 49.

Cho, K.-L., & Jonassen, D. H. (2002). The effects of argumentation scaffolds on argumentation and problem solving. *Educational Technology Research and Development*, *50*(3), 5.

Clemmons, A. W., Timbrook, J., Herron, J. C., & Crowe, A. J. (2020). BioSkills guide: Development and national validation of a tool for interpreting the vision and change core competencies. *CBE—Life Sciences Education*, *19*(4), ar53.

Colvin, W., Lyden, S., & León de la Barra, B. A. (2013). Attracting girls to civil engineering through hands-on activities that reveal the communal goals and values of the profession. *Leadership and Management in Engineering*, *13*(1), 35–41.

Cook, M., & Mulvihill, T. M. (2008). Examining US college students attitudes towards science: Learning from non-science majors. *Educational Research and Reviews*, *3*(1), 038–047.

Cotner, S., Thompson, S., & Wright, R. (2017). Do biology majors really differ from non–STEM majors? *CBE—Life Sciences Education*, *16*(3), ar48.

Crowell, A., & Schunn, C. (2014). Scientifically literate action: Key barriers and facilitators across context and content. *Public Understanding of Science*, *23*(6), 718–733.

Crowell, A., & Schunn, C. (2016). Unpacking the relationship between science education and applied scientific literacy. *Research in Science Education*, *46*(1), 129–140.

Dancy, M., & Henderson, C. (2010). Pedagogical practices and instructional change of physics faculty. *American Journal of Physics*, *78*, 1056–1063.

Dauer, J. M., & Forbes, C. (2016). Making decisions about complex socioscientific issues: A multidisciplinary science course. *Science Education and Civic Engagement*, *8*, 5–12.

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching*, *37*(6), 582–601.

d'I Treen, K. M., Williams, H. T. P., & O'Neill, S.J. (2019). Online misinformation about climate change. *WIRES Climate Change*, *11*, e665. doi: 10.1002/wcc.665

Diekman, A. B., Brown, E. R., Johnston, A. M., & Clark, E. K. (2010). Seeking congruity between goals and roles: A new look at why women opt out of science, technology, engineering, and mathematics careers. *Psychological Science*, *21*(8), 1051–1057.

Ede, A. (2000). Has science education become an enemy of scientific rationality? *Skeptical Inquirer*, *24*(4), 48–48.

Falk, J. H., Storksdieck, M., & Dierking, L. D. (2007). Investigating public science interest and understanding: Evidence for the importance of free-choice learning. *Public Understanding of Science*, *16*(4), 455–469.

Feinstein, N. (2011). Salvaging science literacy. *Science Education*, *95*(1), 168–185. https://doi.org/10.1002/sce.20414

Feinstein, N. W. (2014). Making sense of autism: Progressive engagement with science among parents of young, recently diagnosed autistic children. *Public Understanding of Science*, *23*(5), 592–609.

Fredeen, D. A. (2012). Weaving a tapestry of change: Implementing SENCER on campus. In Sheardy, R., & Burns, W. D. (Eds.), *Science education and civic engagement: The next level* (pp. 31–54). Washington, DC: ACS Publications.

Funk, C., Gottfried, J., & Mitchell, A. (2017). *Science news and information today*. Washington, DC: Pew Research Center. Retrieved on December 14, 2021, from www.journalism.org/2017/09/20/science-news-and-information-today

Funk, C., Rainie, L., & Page, D. (2015). *Public and scientists' views on science and society*. Washington, DC: Pew Research Center. Retrieved December 15, 2021, from www.pewresearch.org/science/2015/01/29/public-and-scientists-views-onscience

General education, finally defined. (2007, March–April 2007). *Harvard Magazine*. Retrieved December 10, 2021, from https://harvardmagazine.com/2007/03/general-education-finall.html#:~:text=General%20education%20is%20the%20place,public%20face%20of%20liberal%20education.%E2%80%9D

Glynn, S. M., Brickman, P., Armstrong, N., & Taasoobshirazi, G. (2011). Science motivation questionnaire II: Validation with science majors and nonscience majors. *Journal of Research in Science Teaching*, *48*(10), 1159–1176.

Goodstein, D. (1992). The science literacy gap: A Karplus lecture. *Journal of Science Education and Technology*, *1*(3), 149–155.

Gormally, C., Brickman, P., & Lutz, M. (2012). Developing a test of scientific literacy skills (TOSLS): Measuring undergraduates' evaluation of scientific information and arguments. *CBE—Life Sciences Education*, *11*(4), 364–377.

Gormally, C., & Inghram, R. (2021). Goggles and white lab coats: Students' perspectives on scientists and the continued need to challenge stereotypes. *Journal of Microbiology & Biology Education*, *22*(1), ev22i1–2273.

Gormally, C. L., & Marchut, A. (2017). "Science is not my thing": Exploring deaf non-science majors' science identities. *Journal of Science Education for Students with Disabilities*, *20*(1), 1–15.

Haffie, T. L., Reitmeier, Y. M., & Walden, D. B. (2000). Characterization of university-level introductory genetics courses in Canada. *Genome*, *43*(1), 152–159.

Hazari, Z., Sadler, P. M., & Sonnert, G. (2013). The science identity of college students: Exploring the intersection of gender, race, and ethnicity. *Journal of College Science Teaching*, *42*(5), 82–91.

Hazen, R. M. (2002). *Why should you be scientifically literate?* Herndon, VA: American Institute of Biological Sciences.

Hebert, S., & Cotner, S. (2019). A comparison of nonmajors' & majors' incoming science process skills. *American Biology Teacher*, *81*(8), 554–560.

Heil, A. D., Brickman, M., & Gormally, C. (2021, July). What do faculty want non-majors to know? Characterizing the content, skills, and stated learning objectives from non-major syllabi. Paper presented at: Society of Advancement in Biology Education Research Conference (conference virtual due to COVID precautions).

Heil, A. D., Gormally, C., & Brickman, P. (in press). Low-level learning: Leaving behind non-science majors. *Journal of College Science Teaching*.

Hewitt, K. M., Bouwma-Gearhart, J., Kitada, H., Mason, R., & Kayes, 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), ar30.

Hilton, S., Hunt, K., & Petticrew, M. (2007). Gaps in parental understandings and experiences of vaccine-preventable diseases: A qualitative study. *Child Care, Health and Development*, *33*(2), 170–179.

Horrigan, J. B. (2006). *The Internet as a resource for news and information about science*. Washington, DC: Pew Research Center. Retrieved December 15, 2021, from www.pewresearch.org/internet/2006/11/20/the-internet-as-a-resource-for-news-and-information-about-science

Hott, A. M., Huether, C. A., McInerney, J. D., Christianson, C., Fowler, R., Bender, ... & Karp, R. (2002). Genetics content in introductory biology courses for non-science majors: Theory and practice. *BioScience*, *52*(11), 1024–1035.

Johnson, A. C. (2007). Unintended consequences: How science professors discourage women of color. *Science Education*, *91*(5), 805–821.

Johnson, M., & Pigliucci, M. (2004). Is knowledge of science associated with higher skepticism of pseudoscientific claims? *American Biology Teacher*, *66*(8), 536–548.

Kahan, D. M., Peters, E., Wittlin, M., Slovic, P., Ouellette, L. L., Braman, D., & Mandel, G. (2012). The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nature Climate Change*, *2*(10), 732–735.

Knight, J. K., & Smith, M. K. (2010). Different but equal? How nonmajors and majors approach and learn genetics. *CBE—Life Sciences Education*, *9*(1), 34–44.

Kua, E., Reder, M., & Grossel, M. J. (2004). Science in the news: A study of reporting genomics. *Public Understanding of Science*, *13*(3), 309–322.

Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education*, *77*(3), 319–337.

Maienschein, J. (1998). Scientific literacy. *Science*, *281*(5379), 917.

MaKinster, J. G., Beghetto, R. A., & Plucker, J. A. (2002). Why can't I find Newton's third law? Case studies of students' use of the Web as a science resource. *Journal of Science Education and Technology*, *11*(2), 155–172.

Millar, R., Osborne, J., & Nott, M. (1998). Science education for the future. *School Science Review*, *80*(291), 19–24.

Miller, J. D. (1998). The measurement of civic scientific literacy. *Public Understanding of Science*, *7*(3), 203.

Miller, J. D. (2004). Public understanding of, and attitudes toward, scientific research: What we know and what we need to know. *Public Understanding of Science*, *13*(3), 273–294.

Miller, J. D. (2010). *The conceptualization and measurement of civic scientific literacy for the twenty-first century. Science and the educated American: A core component of liberal education* (pp. 241–255). Cambridge, MA: American Academy of Arts & Sciences.

Miller, J. D. (2016). *Civic scientific literacy in the United States in 2016*. Ann Arbor, MI: International Center for the Advancement of Scientific Literacy.

Miller, M. C. D., Montplaisir, L. M., Offerdahl, E. G., Cheng, F.-C., & Ketterling, G. L. (2010). Comparison of views of the nature of science between natural science and nonscience majors. *CBE—Life Sciences Education*, *9*(1), 45–54.

Mulkay, M. (1997). Book review of: Misunderstanding science? The public reconstruction of science and technology. *Science, Technology, and Human Values*, *22*(2), 254–264.

National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, DC: National Academies Press. https://doi.org/10.17226/11463

National Center for Education Statistics (NCES). (2013). *Digest of education statistics, 2012* (NCES 2014-015). Washington, DC.

NCES. (2021). *Digest of education statistics, 2019* (NCES 2021-009; chap. 3). Washington, DC.

National Research Council. (1996). *National Science Education Standards*, Washington, DC: National Academies Press.

National Science Foundation. (2014). *Science and engineering indicators*. Arlington, VA.

Opitz, A., Heene, M., & Fischer, F. (2017). Measuring scientific reasoning–a review of test instruments. *Educational Research and Evaluation*, *23*(3–4), 78–101.

Organization for Economic Co-operation and Development. (2003). The *PISA 2003 assessment framework—mathematics, reading, science and problem solving knowledge and skills*. Paris, France: OECD

Orr, D., & Baram-Tsabari, A. (2018). Science and politics in the polio vaccination debate on Facebook: A mixed-methods approach to public engagement in a science-based dialogue. *Journal of Microbiology & Biology Education*, *19*(1). 19.11. 80.

Pellechia, M. G. (1997). Trends in science coverage: A content analysis of three US newspapers. *Public Understanding of Science*, *6*(1), 49.

Puri, N., Coomes, E. A., Haghbayan, H., & Gunaratne, K. (2020). Social media and vaccine hesitancy: New updates for the era of COVID-19 and globalized infectious diseases. *Human Vaccines & Immunotherapeutics*, *16*(11), 2586–2593. doi: 10.1080/21645515.2020.1780846

Rowe, M. P., Gillespie, B. M., Harris, K. R., Koether, S. D., Shannon, L.-J. Y., & Rose, L. A. (2015). Redesigning a general education science course to promote critical thinking. *CBE—Life Sciences Education*, *14*(3), ar30.

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching*, *41*(5), 513–536.

Sargent, J. F., Jr. (2017). *The US science and engineering workforce: Recent, current, and projected employment, wages, and unemployment. Congressional Research Service report prepared for members and committees of Congress*. Washington, DC: Congressional Research Service. Retrieved September 3, 2022, from http://www.fas.org/sgp/crs/misc/R43061.pdf

Schaeffer, K. (2020, July 24) *A look at the Americans who believe there is some truth to the conspiracy theory that COVID-19 was planned*. Washington, DC: Pew Research Center. Retrieved September 3, 2022, from https://www.pewresearch.org/fact-tank/2020/07/24/a-look-at-the-americans-who-believe-there-is-some-truth-to-the-conspiracy-theory-that-covid-19-was-planned/

Schinske, J., Cardenas, M., & Kaliangara, J. (2015). Uncovering scientist stereotypes and their relationships with student race and student success in a diverse, community college setting. *CBE—Life Sciences Education*, *14*(3), ar35.

Schinske, J. N., Perkins, H., Snyder, A., & Wyer, M. (2016). Scientist spotlight homework assignments shift students' stereotypes of scientists and enhance science identity in a diverse introductory science class. *CBE—Life Sciences Education*, *15*(3), 1–18.

Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving*. Boulder, CO: Westview.

Shaffer, J. F., Ferguson, J., & Denaro, K. (2019). Use of the Test of Scientific Literacy Skills reveals that fundamental literacy is an important contributor to scientific literacy. *CBE—Life Sciences Education*, *18*(3), ar31.

Sharon, A. J., & Baram-Tsabari, A. (2020). Can science literacy help individuals identify misinformation in everyday life? *Science Education*, *104*(5), 873–894.

Shauli, S., & Baram-Tsabari, A. (2019). The usefulness of science knowledge for parents of hearing-impaired children. *Public Understanding of Science*, *28*(1), 19–37.

Singer, S. R., Nielsen, N. R., & Schweingruber, H. A. (2012). *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering*. Washington, DC: National Academies Press.

Smith, C. N., & Seitz, H. H. (2019). Correcting misinformation about neuroscience via social media. *Science Communication*, *41*(6), 790–819.

Southwell, B. G., Babwah Brennen, J. S., Paquin, R., Boudewyns, V., & Zeng, J. (2022). Defining and measuring scientific misinformation. *Annals of the American Academy of Political and Social Science*, *700*(1), 98–111. doi: 10.1177/00027162221084709

Speth, E. B., Momsen, J. L., Moyerbrailean, G. A., Ebert-May, D., Long, T. M., Wyse, S., & Linton, D. (2010). 1, 2, 3, 4: Infusing quantitative literacy into introductory biology. *CBE—Life Sciences Education*, *9*(3), 323–332.

Steinberg, M., & Diekman, A. B. (2018). Considering "why" to engage in STEM activities elevates communal content of STEM affordances. *Journal of Experimental Social Psychology*, *75*, 107–114.

Suarez-Lledo, V., & Alvarez-Galvez, J. (2021). Prevalence of health misinformation on social media: systematic review. *Journal of Medical Internet Research*, *23*(1), e17187. doi: 10.2196/17187

Tankard, J. W., Jr., & Ryan, M. (1974). News source perceptions of accuracy of science coverage. *Journalism Quarterly*, *51*(2), 219–225.

U.S. Census Bureau. (2019). U.S. Census Bureau releases new educational attainment data. Retrieved December 15, 2021, from www.census.gov/newsroom/press-releases/2020/educational-attainment.html

Waldo, J. T. (2014). Application of the test of scientific literacy skills in the assessment of a general education natural science program. *Journal of General Education*, *63*(1), 1–14.

Walker, W. R., Hoekstra, S. J., & Vogl, R. J. (2002). Science education is no guarantee of skepticism. *Skeptic (Altadena, CA)*, *9*(3), 24–29.

Walraven, A., Brand-Gruwel, S., & Boshuizen, H. P. (2009). How students evaluate information and sources when searching the World Wide Web for information. *Computers & Education*, *52*(1), 234–246.

Weasel, L. H., & Finkel, L. (2016). Deliberative pedagogy in a nonmajors biology course: Active learning that promotes student engagement with science policy and research. *Journal of College Science Teaching*, *45*(4), 38–45.

West, J. D., & Bergstrom, C. T. (2021). Misinformation in and about science. *Proceedings of the National Academy of Science USA*, *118*(15), e1912444117. https://doi.org/10.1073/pnas.1912444117

Wineburg, S., & McGrew, S. (2017). *Lateral reading: Reading less and learning more when evaluating digital information* (Stanford History Education Group Working Paper No. 2017-A1). Retrieved December 15, 2021, from https://ssrn.com/abstract=3048994

Woloshin, S., & Schwartz, L. M. (2006). Giving legs to restless legs: A case study of how the media helps make people sick. *PLoS Medicine*, *3*(4), e170.