Encouraging Science Communication through Deliberative Pedagogy: A Study of a Gene Editing Deliberation in a Nonmajors Biology Course

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Deliberative pedagogy encourages productive science communication and learning through engagement and discussion of socio-scientific issues (SSI). This article examines a two-day deliberation module on gene editing that took place in an introductory nonmajors biology course, furthering research on integrating deliberative discussion into the biology classroom. The results demonstrate the benefits of a single, episodic deliberation in the classroom, which can positively encourage active discussion and critical awareness of connections between biology and real-world issues, thus contributing to the development of scientific citizenship. Additionally, the findings show that gene editing is an apt SSI topic for the deliberative process because it encourages productive communication practices of scientific citizenship, including discussion, perspective taking, questioning, and consideration of different types of evidence when coming to a decision.

INTRODUCTION

Studies of science communication are often built around knowledge deficit models, or the ways in which scientists communicate research findings to nonscientific publics. These approaches are criticized, however, for their reliance on a one-way flow of information that relegates the public to a passive, disengaged role and minimizes the citizenry’s active engagement in science (1–3). An alternative is to foster active scientific-citizenship habits in students. Scientific citizenship requires both competency in scientific knowledge and active participation in deliberating the future of scientific public issues (4). Such civic engagement employs participatory models that consider the entire “science communication environment,” or the variety of communication processes involving various publics, scientists, governments, businesses, and other stakeholders (3). This more inclusive approach highlights the need to develop the communication skills of all citizens, and in particular the ability of both scientists and nonscientists to discuss public problems and advocate for the best possible solution. A number of researchers have studied the practice of science communication skills is deliberative pedagogy (11). To engage with SSI, deliberative pedagogy uses deliberation, a structured small-group communication process that involves rigorously discussing a public issue, weighing benefits and tradeoffs, while taking into account the perspectives of multiple stakeholders and positions (e.g., Appendix 1). Additionally, deliberation frequently uses an impartial facilitator to guide the discussion, with participants engaging different viewpoints, questioning one another and possible outcomes, identifying tensions in values that must be negotiated, and ultimately, choosing preferred outcomes (12) (e.g., Appendix 1 and 2). In deliberative pedagogy, SSI are referred to as wicked problems, or complex public issues with multiple stakeholders that require coordinated action amongst government, business, and citizens to manage (13–15). The practices of deliberative pedagogy emerged from deliberative democracy, a growing movement that encourages cooperation between government, experts, and the public to address wicked problems, and draws attention to the need for increased public participation through democratic means and collaborative problem-solving (16).
Deliberative pedagogy holds particular promise in promoting the public understanding of science and active scientific citizenship because it fosters contextual and participatory science communication, encouraging dialogue between the positions and concerns of multiple stakeholders. It also encourages developing the means for civic action through judgment, when, after discussing and questioning an issue, participants make a decision about how to move forward; such a judgment may be a policy preference, but might also be coordinated actions among multiple stakeholders designed as first steps to address the problem. Deliberation over SSI encourages science communication to focus on collaborative exchange rather than dissemination (17). In science classrooms, small-group deliberation activities have been shown to encourage participation of all students and to promote skills like interaction with scientific public issues, critical thinking, application, and problem solving (18–20).

Because of these benefits, deliberative pedagogy is a growing area of research within science education. Many colleges and universities focus on developing scientific citizenship and science communication skills in most potential members of the “science communication environment” through dedicated science courses for nonmajors. These courses introduce students to many of the same foundational concepts of the discipline taught in introductory courses for science majors, but because they are often standalone courses, not meant to prepare students for subsequent coursework, instructors may have greater latitude to focus on skills or content specifically designed to develop scientific literacy and/or scientific citizenship (21, 22). Participatory models of science communication can be particularly beneficial in these contexts: students in nonmajors’ science courses may have, on average, a lower initial level of content expertise and problem-solving abilities (23) and lower initial interest in the science subject area (23, 24), relative to students planning to major in science. Unsurprisingly, studies have demonstrated that best practices for educating nonscience majors include increasing interactivity during class sessions (25) and devoting class time to activities that explicitly address real-world applications of course material (22, 26, 27) or ethical considerations associated with technological innovations (28). Such strategies are consistent with influential recommendations for biology curricula (29) and may be achieved by giving students practice with participatory forms of science communication. Two previous studies explored reorienting nonmajors’ science courses entirely around deliberative pedagogies and reported strong gains in student knowledge and in positive perceptions of biology (18, 19). Recognizing that not all instructors may feel confident enough or be able to alter their entire course focus, this study furthers research on deliberation in the biology classroom by investigating a deliberation module. Unfortunately, students are often not equipped with what Carcasson has called “deliberative skills,” or the ability to “engage the natural tensions, trade-offs, tough choices, dilemmas, and paradoxes embedded in issues,” while incorpor-

porating experiences, beliefs, values, and technical information (30). Deliberation in classroom settings encourages the development of oral communication and critical thinking as students learn to productively discuss tensions, evaluate potential options, and develop judgments for how to address SSI/wicked problems (11).

This research looks at a two-day deliberation module within a nonmajors biology course, offering insights on a shorter deliberative-pedagogy exercise. Additionally, the topic directly engages a timely SSI/wicked problem: genetic engineering of humans, a topic previously identified as apt for student discussions due to its ethical and moral complications (6). The deliberation activity for this study was designed to encourage civically engaged science communication, which includes active, on-topic discussion of the issue; perspective-taking through speaking and listening to diverse views; and recognition of different types of evidence and values when making a decision. Additionally, the deliberation should work to develop students’ civic skills and improve student attitudes toward science and public problem solving. We therefore pose two research questions: 1) Did the deliberation module promote engaged science communication? and 2) How did the deliberation module impact student perceptions of scientific public problems? Both of these research questions assess how deliberating a SSI encourages the development of science communication skills, which in turn promotes scientific citizenship.

METHODS

The course and the deliberation module

The gene editing deliberation module took place in a nonmajors biology course (BIO-101, Human Biology) at Wabash College, a small liberal arts college for men located in Indiana. BIO-101 is a course designed to help students majoring in the humanities or social sciences develop an understanding of the process of scientific inquiry and the role of science in their lives. Instructors use a variety of pedagogical strategies ranging from lectures with varying levels of interactivity, to small-group discussions of readings or case studies, to laboratory assignments.

The deliberation module occurred during the sixth week of the semester in spring 2016, fall 2016, and spring 2017, at the end of a three-week unit on genetics and inheritance in humans. The first day of the module—taught by a different instructor each semester and with slightly different emphases depending on the individual’s preferences—consisted of a lecture on gene editing methods. Common foundational material included an introduction to DNA structure and basic information on key methods used to alter the nuclear genome (e.g., zinc finger nucleases, TALENs, CRISPR-Cas9), emphasizing the advantages of CRISPR-Cas9 over previous approaches. Students in fall 2016 were also assigned readings about gene editing techniques (31, 32) and a podcast (33) to complement the lecture material.
The second part of the module included a one-class-
session deliberation on the ethical consequences of human
gene editing using a customized issue guide developed by
the course faculty and students trained in deliberation
(Appendix I). The issue guide was modeled on issue guides
produced by organizations such as the National Issues
Forum, Public Agenda, and the Kettering Foundation (34).
It framed the deliberation around the question, “Should
the gene editing technology be used in humans?” and de-
scribed three options for deploying these technologies: 1)
few/no restrictions, allowing a wide range of gene editing
in humans, including phenotypic enhancement; 2) restrict-
ing gene editing technologies to therapeutic use only; and
3) a complete ban on gene editing in humans. Each option
included a realistic scenario to help students understand
the consequences of that regulatory regime as well as po-
tential benefits and concerns associated with that choice.
Students in the course broke into small groups (of 6 to 8
students) and used the issue guide to deliberate for the
50-minute class session, led by student facilitators. The
facilitators had received training through either a course in
deliberation offered by the Rhetoric Department or through
work with the Wabash Democracy and Public Discourse
initiative, an interdisciplinary program focusing on public
dialogue and deliberation. This training followed common
practices for facilitation and encouraged an open space for
all to participate, make statements, and question throughout
the deliberation (35, 36). The facilitators met prior to the
deliberation to discuss strategies; they also used a common
facilitation guide to encourage similar conversations across
all groups (Appendix 2). The strategy stressed engaging dif-
ferent perspectives and values, asking responsive questions
that reflected the issue and the group’s discussion, and
encouraging all to participate.

Students were given a pre-deliberation survey after the
lecture but before the deliberation. Questions on the survey
gauged attitudes about biology, scientific public problems,
and civic engagement and used a 5-point Likert scale. The
post-deliberation survey was administered after the delib-
eration; in addition to the questions contained in the initial
survey, the post-deliberation survey contained questions
about the quality of deliberation (using a 5-point Likert scale)
and qualitative questions to assess whether students felt the
discussion was active and productive. Students were given
participation points for their attendance and for taking the
surveys. The Wabash College Institutional Review Board
approved all research for this study, and all participants gave
informed consent. The survey questions were adapted from
previous studies of deliberative democracy and deliberative
pedagogy (37–39).

Statistical analysis

To determine the added value of the deliberation com-
ponent of the module relative to the lecture, we measured
changes in students’ attitudes in three categories, using
data from 16 questions repeated on both the pre- and
post-deliberation survey (Table 1). These three categories
connect with the learning goals for the deliberation. To ad-
dress the learning goal of active discussion, students were
surveyed on their perceived ability to discuss topics in
logical, evidence-based ways (Logical Discussion). To con-
nect with the learning goal of improving student attitudes
ward science, students were asked about their interest
in, and enthusiasm for, biology (Biology Interest). Finally,
students were asked about their understanding of biology
as interconnected with real-world issues (Interconnected-
ness), reflecting the goal of fostering civic skills through an
understanding of SSI.

Each student's pre-deliberation scores for the questions
in each assessment category were aggregated to a single
pre-deliberation score per category; post-deliberation
scores were similarly aggregated, allowing us to compare
the aggregated pre and post scores for each student, for
each category. Across the three semesters, 88 students
(40 in spring 2016, 24 in fall 2016, and 24 in spring 2017)
participated in the deliberation and completed both surveys.
However, some students skipped one or more questions;
these students’ data were included only if they had answered
all the questions in a category. The scores of any students
who missed a question in a category were omitted from the
aggregated score and subsequent analysis for that category.

Pre and post data were analyzed by a two-way mixed
ANOVA in which the within-subjects variable was the pre and
post measurement, and the between-subjects variable was
the cohort year. This analysis enabled us to assess whether
any significant pre versus post changes were moderated by
cohort, an important consideration since each cohort was
taught by a different faculty member and deliberations were
led by different small-group student facilitators.

Critical-interpretative analysis

The post-deliberation survey included a series of
open-response questions designed to address the research
questions using student and instructor reflections on the
deliberation module experience. Students were asked to
identify the issues discussed in the deliberation, up to
three things they learned during the deliberation, the most
challenging part of addressing this issue, and what should
be done and why. Applied rhetorical criticism (40) was used
to analyze substantial themes in the responses to these
question. This method employs rigorous consideration of
textual meaning through close analysis. Additionally, as this
critical-interpretative methodology appreciates and draws
on the interaction of context and textual meaning, instructor
and facilitator reflections on the deliberations were used to
ground the interpretation of themes, following established
practices of analyzing deliberative communication and re-
solving differences through a group judgment of the research
team (41). This allowed the research team to consider how
the deliberation prompted science communication.
RESULTS

Engaged science communication through deliberation

The first research question was about whether this in-class deliberation would promote student engagement in science communication. The statistical and critical-interpretative analysis of the surveys and instructor/facilitator observations indicate that the activity succeeded in encouraging students to develop a “deliberative mind set” (30) for scientific citizenship and that the deliberation encouraged students to see themselves as doing the communicative work of scientific citizenship while practicing the habits of civically engaged science communication. Answers to the open-ended survey questions reflect students’ engagement with the tensions of an SSI, such as benefits and tradeoffs, value tensions, and uncertainty. Students reported discussing “the positive and negative effects of gene editing” and the “pros and cons of the three choices while thinking deeply on the real-world consequences of each.” The survey responses and facilitator and instructor observations suggested that students expressed and listened to a number of perspectives, even beyond the those presented in the issue guide (Appendix 1). For example, one student shared that in their group, “One person wanted to allow gene editing to be completely open to allow advancement of humans. A couple [of] people wanted therapeutic use only, and a couple [of] people thought that we should not gene edit at all.” Other responses demonstrated that the deliberation encouraged students to analytically process what they were hearing, which resulted in considering diverse positions and evidence; one student reflected the task was “to consider what was best for our population without using biased opinions or positions.”

Survey responses also demonstrated respect for diverse ideas and positions after the deliberation. Respect for others’ positions is a key learning outcome of deliberative pedagogy, as it helps citizens develop more-informed positions that take into account others’ concerns (42); it also encourages an understanding of the roles of scientific knowledge and ethical argument in SSI. For example, one student wrote, “I have high optimism in the human race, I believe that this technology could provide incredible benefits for the human race, however I also understand that other people may not be as optimistic as I am.” Based on the analysis, students orally exchanged and evaluated diverse perspectives, and listened to views other than their own.

 Across the three cohorts, a statistical analysis of survey data collected before and after the in-class deliberation demonstrated no improvement in students’ self-reported ability to discuss scientific topics logically, with no significant differences among cohorts, either within or between subjects (Table 2). However, while students might not have
TABLE 2.
Impact of deliberation on students’ views of gene editing.

|                      | Interconnectedness | Logical Discussion | Biology Interest |
|----------------------|--------------------|--------------------|------------------|
| Pre-deliberation mean ± standard deviation | 16.6 ± 3.4         | 28.1 ± 4.1         | 9.9 ± 3.1        |
| Post-deliberation mean ± standard deviation | 17.7 ± 3.3         | 27.9 ± 4.2         | 10.4 ± 3.1       |

Within-subject effects:

- Pre- vs. post-deliberation \( ^a \) \( p = 0.004 \)
- Pre- vs. post-deliberation, by cohort year \( ^b \) \( p = 0.792 \)
- Between-subject effect: impact of cohort year \( ^c \) \( p = 0.955 \)

Pre- and post-deliberation means and standard deviations were calculated for each assessment category, across all three cohorts. For each category, the mixed ANOVA was used to test the effect of the deliberation alone (a), the cohort alone (b), or the extent to which the pre- versus post-deliberation difference was moderated by cohort (c).

rated themselves as improving in logical discussion, other data nevertheless suggest that students were actively engaged in scientific discussion. Informal instructor observations of the three in-class deliberations suggested that the activity was highly participatory, with all students actively discussing. The survey responses confirmed instructor and facilitator observations that the deliberations largely stayed within the issue framework and on task. Students also rated the quality of deliberation highly through post-survey questions relating to productive discussion principles. Students in all three cohorts gave above-average ratings on several measures, including “listened to other ideas and perspectives” (averages of 4.20, 4.29, and 4.26 out of 5); “carefully considered my own view in light of new perspectives and information” (averages of 3.91, 4.08, and 4.13 out of 5); and “the discussion in my group was productive” (averages of 4.08, 4.33, and 4.29 out of 5).

Student perceptions of scientific public problems

An important outcome of deliberation is for participants to recognize the role of science in real-world problems, which in turn should prompt recognition of the importance of scientific coursework (9, 10). Analysis of survey responses collected from all three cohorts showed a statistically significant increase in students’ perceptions of a connection between biology and real-world issues (effect of pre versus post: \( F(1, 83) = 8.954, p = 0.004 \), not moderated by cohort year), as well as a modest but not significant increase in students’ interest in biology (pre versus post: \( F(1, 86) = 2.748, p = 0.101 \); Table 2). There were no significant differences among cohorts, either within or between subjects (Table 2). The statistical analysis therefore suggests support for improving attitudes toward science and developing civic skills relating to scientific citizenship.

Critical-interpretative analysis of the open-ended survey questions demonstrated that students engaged the technical complexity and ethical components of the SSI. In their answers to these questions, a majority of students remarked on their group’s discussion of ethical considerations. Specifically, the responses demonstrate that ethics were discussed in the context of particular and general cases; some students shared that their deliberation included questions of situational ethics, morality, socioeconomic issues, medical health, and business. Student responses acknowledged that the issue had an impact not only on them but also on the future of their society: for example, one student shared that decisions about gene editing would impact “future generations without their consent,” and another commented, “We discussed how society may change if it is actually implemented.”

Some responses also drew attention to the complexity of the issue by acknowledging that the group did not have sufficient scientific expertise to discuss the topic. When asked what was challenging about this topic, one example response was “not having enough knowledge about gene editing,” and another was “gaining enough knowledge on the subject to make informed assessment.” This followed the facilitators’ observations that students did engage scientific content as they discussed the issue, but also that they recognized the limits of their knowledge and the many unknowns (even to scientists) related to technical issues of deploying gene editing in humans.

Additionally, the post-deliberation survey contained an open-response question asking students what should be done. The process of deliberation encourages participants to discuss a problem and multiple responses to it, and then decide a way forward (12, 43). In this case, the “way forward” was expressed in the final part of the deliberation when the facilitator asked the group for their preferences, and then a second time on the surveys to provide an opportunity for individual responses. Thus, students coming to decisions is a productive communication outcome of the deliberation activity. When asked in the post-deliberation survey what the first/preferred action should be, student responses largely fell into five themes: 1) further scientific research; 2) further ethical/moral research and understanding; 3) setting boundaries or creating regulations; 4) encouraging greater
public understanding of the issue through education and deliberation; and 5) banning gene editing. While these themes reflected material that was present in the deliberation issue guide, many students’ responses included additional justification that clearly drew on their group’s discussion of balancing benefits and consequences. Students’ decisions were often informed by scientific knowledge and ethics, as well as information from other fields such as economics, politics, and religious studies.

**DISCUSSION**

This study advanced deliberative pedagogy as a form of science communication about a specific public problem, namely the use of gene editing in humans. The surveys and observational data demonstrate that students actively discussed the SSI, recognizing scientific complexity and ethical dilemmas. This suggests that the argumentative depth possible during deliberation is particularly well suited for encouraging prolonged exchanges in interactive oral communication. Such interaction prompts students to work together and consider the value and implications of scientific and ethical argumentation (44, 45). Future research should analyze the particular argumentation strategies of classroom-based deliberations on SSI, connecting deliberative pedagogy with existing research on science communication and argumentation in classrooms. Further research would add understanding to how scientific expertise and ethics intersect in public discourse.

The analysis of this activity demonstrates that facilitated deliberations, and the communication that takes place amongst participants, can support the development of engaged scientific citizenship. Students gained greater awareness of other positions, as evidenced by their survey responses. Additionally, students came away with greater awareness of connections between biology and real-world issues (Table 2). Consistent with biology education’s desire to push past the simplistic, one-way communication of scientific issues to the public, deliberation prompts participatory forms of science communication—diverse engagement and co-creation of knowledge involving scientists and the public (28, 29, 43). The high frequency of student survey responses recommending further research, education, and discussion as the first step to addressing the issue at hand suggests that the deliberation on gene editing encouraged students to see the SSI as an issue for ongoing collaboration amongst stakeholders such as scientists, the public, business, and government.

This research focused on the science communication impacts of a shorter deliberation activity, unlike previous studies with a semester-long deliberation focus (18, 19), where students also showed elevated scientific content learning gains. To see whether deliberation enhanced comprehension beyond the lecture, we did test for student understanding of the mechanics of gene editing techniques before and after the deliberation, but no significant improvements were found (data not shown). This result was not particularly surprising given the ethical, rather than scientific, focus of the issue guide (Appendix 1) and the discussions thus stimulated. However, for faculty interested in using deliberation as a way of encouraging engaged scientific citizenship and discussion-based science communication, the learning gains in civically engaged science communication and an increased awareness of real-world connections between scientific knowledge (in this case, genetic engineering) and public issues may justify the use of a deliberation module. Future research on deliberative pedagogy should consider the differences between small-scale injections of deliberative pedagogy and more holistic integration of this approach in biology courses, as well as which methods within the full scope of deliberative pedagogy would increase student knowledge gains (11). Additionally, instructors and future studies may wish to modify their internal assessment of deliberative pedagogy based on their particular learning goals.

As a rhetorical form, deliberation encourages an interactive, participatory model of science communication about scientific and ethical wicked problems (9, 20, 30). Deliberative pedagogy is important for scientific and biological undergraduate education today because many challenging problems of the future will require collaborations between scientists and nonscientists in an ever-changing landscape of rapid technological innovation (17, 44, 45). The results here demonstrate that incorporating deliberation about an SSI into an introductory nonmajors biology course fosters a mindset that encourages civically engaged science communication habits. Deliberation in undergraduate science courses prepares students to study, discuss, and critically evaluate public problems, providing a foundation for productive communication as a way to embody active scientific citizenship.

**SUPPLEMENTAL MATERIALS**

Appendix 1: Issue guide
Appendix 2: Facilitation guide

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**REFERENCES**

1. Simis MJ, Madden H, Cacciatore MA, Yeo SK. 2016. The lure of rationality: why does the deficit model persist in science communication? Public Underst Sci 25:400–414.
2. Suldovsky B. 2016. In science communication, why does the idea of the public deficit model always return? Exploring key influences. Public Underst Sci 25:415–426.

3. Kahan D, Scheufele DA, Jamieson, KH. 2017. Introduction: why science communication?, p 1–11. In Jamieson KH, Kahan D, Scheufele DA (ed), The Oxford Handbook of the Science of Science Communication. Oxford University Press, New York, NY.

4. Mejía-Gaard N, Stares S. 2010. Participation and competence as joint components in a cross-national analysis of scientific citizenship. Public Underst Sci 19:545–561.

5. Gross A. 1994. The roles of rhetoric in the public understanding of science. Public Underst Sci 3:3–23.

6. Sadler TD, Zeidler DL. 2004. The morality of socio-scientific issues: construal and resolution of genetic engineering dilemmas. Sci Ed 88:4–27.

7. Bauer MW, Allum N, Miller S. 2007. What can we learn from 25 years of PUS survey research? Liberating and expanding the agenda. Public Underst Sci 16:79–95.

8. N. What’s next for science communication? Promising directions and lingering distractions. Am J Bot 96:1767–1778.

9. Sadler TD. 2009. Situated learning in science education: socio-scientific issues as contexts for practice. Studies Sci Educ 45:1–42.

10. Grooms J, Sampson V, Golden B. 2014. Comparing the effectiveness of verification and inquiry laboratories in supporting undergraduate science students in constructing arguments around socio-scientific issues. Int J Sci Educ 36:1412–1433.

11. Shaffer Tj, Longo NV, Manosevitch I, Thomas M (ed). 2017. Deliberative pedagogy: teaching and learning for democratic engagement. Michigan State University Press, Lansing, MI.

12. Gastil J. 2008. Political communication and deliberation. Sage Publications, Thousand Oaks, CA.

13. Rittole HWJ, Webber MW. 1973. Dilemmas in a general theory of planning. Policy Sci 4:155–169.

14. Pidgeon N, Demske C, Butler C, Parkhill K, Spence A. 2014. Creating a national citizen engagement process for energy policy. Proc Natl Acad Sci USA 111:13606–13613.

15. Kronberger N, Holtz P, Wagner W. 2012. Consequences of media information uptake and deliberation: focus groups’ symbolic coping with synthetic biology. Public Underst Sci 21:174–187.

16. Nabatchi T. 2012. An introduction to deliberative civic engagement, p 3–18. In Nabatchi T, Gastil J, Weiksnar GM, Leighninger M (ed), Democracy in motion. Oxford University Press, New York, NY.

17. Dietz T. 2013. Bringing values and deliberation to science communication. Proc Natl Acad Sci USA 110:14081–14087.

18. Tinsley HN. 2016. Ripped from the headlines: using current events and deliberative democracy to improve student performance and perceptions of nonmajors biology courses. J Microbiol Educ 17:380–388.

19. Weasel LH, Finkel L. 2016. Deliberative pedagogy in a nonmajors biology course: active learning that promotes student engagement with science policy and research. J Coll Sci Teach 45:38–45.

20. Drury SAM. 2015. Deliberation as communication instruction: a study of a climate change deliberation in an introductory biology course. J Excel Coll Teach 26:51–72.

21. Scharmann LC, Harty H. 1986. Shaping the nonmajor general biology course. Am Biol Teach 48:166–169.

22. Nastase AJ, Scharmann LC. 1991. Nonmajors’ biology: enhanced curricular considerations. Am Biol Teach 53:31–36.

23. Semsar K, Knight JK, Birol G, Smith MK. 2011. The Colorado learning attitudes about science survey (CLASS) for use in biology. CBE Life Sci Educ 10:268–278.

24. Knight JK, Smith MK. 2010. Different but equal? How nonmajors and majors approach and learn genetics. CBE Life Sci Educ 9:34–44.

25. Ernst H, Colthorpe K. 2007. The efficacy of interactive lecturing for students with diverse science backgrounds. Adv Physiol Educ 31:41–44.

26. Wright RL. 2005. Undergraduate biology courses for nonscientists: toward a lived curriculum. Cell Biol Educ 4:189–196.

27. Garcia R, Rahman A, Klein JG. 2015. Engaging non-science majors in biology, one disease at a time. Am Biol Teach 77:178–183.

28. Johansen CK, Harris DE. 2000. Teaching the ethics of biology. Am Biol Teach 62:352–358.

29. American Association for the Advancement of Science. 2011. Vision and change in undergraduate biology education: a call to action: a summary of recommendations made at a national conference organized by the American Association for the Advancement of Science, July 15–17, 2009. Washington, DC.

30. Carcasson M. 2017. Deliberative pedagogy as critical connective: building democratic mind-sets and skill sets for addressing wicked problems, p 3–20. In Shaffer Tj, Longo NV, Manosevitch I, Thomas M (ed), Deliberative pedagogy: teaching and learning for democratic engagement. Michigan State University Press, Lansing, MI.

31. Ledford H. 2015. CRISPR, the disruptor. Nature 522:20–24.

32. Callaway E. 2014. The power of three. Nature 509:414–417.

33. Radiolab. 2015. Antibodies Part I: CRISPR, www.radiolab.org/story/antibodies-part-1-crispr/.

34. Rourke B. 2014. Developing materials for deliberative forums. The Kettering Foundation Press, Dayton, OH.

35. Diebel A. 2016. Facilitating public issues: best practices. National Issues Forum https://www.nifi.org/en/catalog/product/facilitating-public-issues-best-practices-alice-diebel.

36. Community Tool Box. 2017. Chapter 16, Group facilitation leadership/group-facilitation.

37. Gastil J, Xenos M. 2010. Of attitudes and engagement: clarifying the reciprocal relationship between civic attitudes and political participation. J Commun 60:318–343.

38. Gastil J, Black L, Moscovitz K. 2008. Ideology, attitude change, and deliberation in face-to-face groups. Polit Commun 25:23–46.

39. Drury SAM, Stucker K, Douglas A, Rush RA, Novak WR, Wyszocki LM. 2016. Using a deliberation of energy policy as an educational tool in a nonmajors chemistry course. J Chem Educ 93:1879–1885.
40. Condit CM, Bates BR. 2009. Rhetorical methods of applied communication scholarship, p 270–290. In Cisna KL, Frey LR (ed), Handbook of applied communication research. Lawrence Erlbaum Associates, Mahwah, NJ.

41. Asen R, Gurke D, Connors P, Solomon R, Gumm E. 2013. Research evidence and school board deliberations. Educ Policy 27:33–63.

42. Drury SAM, Brammer LR, Doherty J. 2017. Assessment through a deliberative pedagogy learning outcomes rubric, p 191–201. In Shaffer TJ, Longo NV, Manosevitch I, Thomas M. (ed), Deliberative pedagogy: teaching and learning for democratic engagement. Michigan State University Press, Lansing, MI.

43. Lindell TJ, Miczarek GJ. 1997. Ethical, legal, and social issues in the undergraduate biology curriculum: encouraging student debate on the social implications of biotechnology. J Coll Sci Teach 26:345–349

44. Von Winterfeldt D. 2013. Bridging the gap between science and decision making. Proc Natl Acad Sci U S A 110:14055–14061.

45. Gastil J. 2017. Designing public deliberation at the intersection of science and public policy, p 233–242. In Jamieson KH, Kahan D, Scheufele DA (ed), The Oxford handbook of the science of science communication. Oxford University Press, New York, NY.