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 how to promote productive engagement of socio-scientific issues (SSI), which typically involve ethical and scientific concerns. Their findings suggest that it is useful in teaching science communication to stress the active, communicative habits of citizenship, habits which bring the public into discussion of SSI (5–10). These researchers provide some recommendations for building such skills in the classroom or laboratory, but there remains an opportunity to create classroom discussions of SSI that foster science citizenship by mimicking the real-world political environment.

One model for encouraging active scientific citizenship through 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).

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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 incorporating 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 1). 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 described three options for deploying these technologies: 1) few/no restrictions, allowing a wide range of gene editing in humans, including phenotypic enhancement; 2) restricting 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 potential 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 different 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 deliberation; 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 component 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 address the learning goal of active discussion, students were surveyed on their perceived ability to discuss topics in logical, evidence-based ways (Logical Discussion). To connect with the learning goal of improving student attitudes toward 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 (Interconnectedness), 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 resolving 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 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>
<thead>
<tr>
<th>Assessment Category</th>
<th>Survey Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interconnectedness</td>
<td>Presently, I understand ...</td>
</tr>
<tr>
<td>Logical Discussion</td>
<td>Presently, I can ...</td>
</tr>
<tr>
<td>Biology Interest</td>
<td>Presently, I am ...</td>
</tr>
</tbody>
</table>

Response options for the questions in these categories were as follows: 0 = n/a, 1 = not at all, 2 = just a little, 3 = somewhat, 4 = a lot, 5 = a great deal.
TABLE 2.
Impact of deliberation on students' views of gene editing.

<table>
<thead>
<tr>
<th></th>
<th>Interconnectedness</th>
<th>Logical Discussion</th>
<th>Biology Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-deliberation mean ± standard deviation</td>
<td>16.6 ± 3.4</td>
<td>28.1 ± 4.1</td>
<td>9.9 ± 3.1</td>
</tr>
<tr>
<td>Post-deliberation mean ± standard deviation</td>
<td>17.7 ± 3.3</td>
<td>27.9 ± 4.2</td>
<td>10.4 ± 3.1</td>
</tr>
</tbody>
</table>

Within-subject effects:

- Pre-vs. post-deliberation
  - $p = 0.004$
  - $p = 0.946$
  - $p = 0.101$

- Pre-vs. post-deliberation, by cohort year
  - $p = 0.792$
  - $p = 0.489$
  - $p = 0.967$

- Between-subject effect: impact of cohort year
  - $p = 0.955$
  - $p = 0.771$
  - $p = 0.103$

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

**ACKNOWLEDGMENTS**

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