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Embracing the inclusion of societal concepts in biology improves student understanding

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Understanding the relationship between science and society is included as a core competency for biology students in the United States. However, traditional undergraduate biology instruction emphasizes scientific practice and generally avoids potentially controversial issues at the intersection of science and society, such as representation in STEM, historical unethical research experiments, biology of sex and gender, and environmental justice. As calls grow to highlight this core competency, it is critical we investigate the impact of including these topics in undergraduate biology education. Here, we implemented a semester-long *ideological awareness* curriculum that emphasized biases, stereotypes, and assumptions that have shaped historical and contemporary science. We taught this curriculum to one section of a non-majors introductory biology course and compared the outcomes to a section of the same course taught using traditional biology content (hereafter the 'traditional' section) that did not emphasize societal topics. Both sections of students created concept maps for their final exam, which we coded for 'society' and 'biology' content. We then assessed (1) the amount of societal content included in the concept maps, and (2) which societal topics were mentioned in each section. We found that students in the ideologically aware section included more societal content in their concept maps than the students in the traditional section. Students exposed to the ideological awareness modules often mentioned the topics covered in those modules, whereas students in the traditional section most commonly mentioned faulty scientific information such as pseudoscience or non-credible research, which was emphasized in the first chapter of the required text-book for both sections. Our results show students who were not engaged in activities about ideological awareness in biology had fewer notions of how society impacts science at the end of the semester. These findings highlight the importance of intentionally teaching students the bidirectional impacts of science and society.

KEYWORDS

ideological awareness, culturally relevant pedagogy, concept maps, life sciences, biology, undergraduate education, inclusive pedagogy, STEM education

1. Introduction

Reimagining biology education to teach science to all students includes emphasizing the impacts of society on science. For example, damaging ideologies that have influenced science, from eugenics to unethical experimentation, cannot be challenged if they remain concealed in our teaching. Presenting a 'value-free' interpretation of biology – defined by its content and certainty, and without influence of personal values– suggests these values have no influence on the conduct of science and that scientists should have little concern for such values (Cross and Price, 1996; Douglas, 2009). This message harms students who have historically been exploited in the name of science and not had access to careers in science (Gould, 1996; Asai, 2020; Canfield et al., 2020; Beatty et al., 2021). To address the inextricable link between science and society, the Vision and Change report formalized priorities and outlined several core competencies intended to guide undergraduate biology education, including students' ability to understand the relationships between science and society (American Association for the Advancement of Science, 2011). Given that a similar call for intervention in K-12 education, made by the National Research Council (2012) it is clear that many students are not receiving instruction at any level concerning the relationships between science and society. For this reason, we took action where we could: the college level. Specifically, we developed an undergraduate biology curricula that focuses on how human values and ideologies impact science. As Gould (1996) wrote: "Science, since people must do it, is a socially embedded activity" (p. 53).

Culturally relevant pedagogy is an evidence-based theoretical framework that can be used to integrate societal aspects into science curricula (Ladson-Billings, 1992, 1995a,b, 2006). Ladson-Billings defines culturally relevant teaching as a "pedagogy of opposition" (Ladson-Billings, 1995a,b), that "empowers students to […] examine critically educational content and process and ask what its role is in creating a truly democratic and multicultural society" (Ladson-Billings, 1992). This theoretical framework rests on three criteria: (1) student academic success, (2) cultural competence, and (3) sociopolitical consciousness. While work on culturally relevant pedagogy has historically focused on promoting student academic success and cultural competence (i.e., teaching students who do not share one's same personal characteristics or the same cultural background; Tanner and Allen, 2007), less work has focused on sociopolitical consciousness (i.e., addressing structural inequities and challenging injustices; Ladson-Billings, 1995a,b, 2014; Young, 2010).

Ideological awareness, a type of culturally relevant pedagogy, focuses on addressing structural inequities and challenging injustices in the context of biology (Potochnik, 2020;Beatty et al., 2021; Costello et al., 2023). Specifically, the ideological awareness curriculum communicates how biases, stereotypes, and assumptions have informed approaches to and outcomes of contemporary and historical science (Beatty et al., 2021; Costello et al., 2023). Activities that emphasize the relationship between science and society create more transparent, scientifically accurate, and inclusive postsecondary biology classrooms (Costello et al., 2023). These lessons encourage students to question and critique structural inequalities and injustices within scientific research (Ladson-Billings, 1995b, 2014; Young, 2010; Costello et al., 2023). Additionally ideological awareness can be implemented as a way to bring societal, real-world context to traditional biology lectures, promoting a more complete understanding of how science interacts with society (Beatty et al., 2021, Costello et al., 2023). For more information about the background and application of ideological awareness, we recommend Costello et al. (2023).

Previous work using ideological awareness curriculum has shown that undergraduate biology students are generally uninformed on the intersecting qualities of biology and society (Beatty et al., 2021). For example, nearly half of the biology students in an introductory biology class in the Southeast United States were not previously aware of topics related to unethical biological experimentation on people, or related to issues surrounding representation in science, technology, engineering, and mathematics (STEM) disciplines (Beatty et al., 2021). While the authors considered the possibility that addressing difficult societal issues (e.g., representation in STEM, environmental racism) might negatively impact persons excluded because of their ethnicity or race (PEERs; Asai, 2020), findings showed that across all the course modules, PEER students were more likely to approve of the inclusion of the materials (Beatty et al., 2021). The authors concluded the ideological awareness curriculum may be an appropriate method for teaching biology students about the intersection of science and society; however, more research is needed to investigate how this curriculum impacts students' ability to make connections between science and society.

Here, we measured students' ability to relate biology content and societal issues after being taught with an ideological awareness curriculum. We compared these students and their ability to relate biology to society to a second section of the same class that received traditional non-majors biology content. We used concept mapping as a tool and proxy to assess students' knowledge of ideologically aware society topics with biology content. We compare the amount of biology and society content in the concept maps of both course sections, and quantify the specific societal topics mentioned. Specifically, we address the following research questions:

1. Does exposure to ideological awareness materials increase the amount of biological and/or societal content mentioned in student concept maps, compared to students who were not exposed to ideological awareness materials?
2. What societal topics were students most likely to mention in the ideologically aware section and the traditional section?

2. Materials and methods

2.1. Student population and class setting

We collected data from two sections of a non-majors introductory biology course taught at a public university in the southeastern United States during 2021. The total number of enrolled students in the course was 54 (i.e., 25 in the ideologically aware section and 29 in the traditional section) with 16 participating students from the ideologically aware section and 20 participating students from the traditional section. We collected self-reported demographic data in an end-of-course survey. Due to small sample sizes, to protect student privacy, here we report general demographic trends across the two classes. The gender of the participating students was approximately half women and half men across both classes; each section consisted predominately of White and Black/African American students in equal proportions; and the majority (~77%) of students enrolled were lower-division students (i.e., first-and second-year students). Both sections of the introductory biology course were taught twice-weekly in-person for a period of 75-min. Coauthor AEB instructed the ideologically aware section and coauthor PR taught the traditional section. While each section was taught by a different instructor, the same institutional standards for learning objectives and materials were covered in each course.

2.2. Traditional class description

The traditional section received traditional lecture instruction via PowerPoint. These PowerPoints were derived from the required student textbook "Biology Now with physiology" (Houtman et al., 2020). Additionally, students were assigned pre-class readings from the textbook, covering traditional biology content through relevant stories with a focus on scientific literacy for nonmajor students. Student grades consisted of four tests (65.57% of the total), three quizzes (12.3%), in-class points (8.20%), and homework (13.93%). The fourth and final exam included a multiple-choice exam and the concept map exercise described in the "Student Concept Mapping" section below.

2.3. Ideological awareness class description

The ideological awareness section used a flipped classroom format (Lage et al., 2000). In the flipped classroom format, traditional lectures were pre-recorded and watched online prior to class. Then, during class time, students completed active learning activities relating to both science and societal topics. Approximately half of the active learning activities focused on science content, while the remaining 50% of active learning activities addressed the link between the biology curriculum and the societal implications of science, including ~15% of time spent on student presentations (see "Ideological Awareness Adaptations" section; Table 1). Additionally, AEB assigned required readings from "The Immortal Life of Henrietta Lacks" over the course of the semester (Skloot, 2010). Notably, the "Biology Now with physiology" textbook was still required for this section, but the readings were optional, acting only as an additional resource for the students (Houtman et al.). Grades consisted of presentations (10%), written reflections (10%), quizzes (30%), homework and assignments (25%), participation (20%), and a final exam (5%). The final exam included the concept map exercise described in the "Student Concept Mapping" section below.

2.4. Ideological awareness adaptations

In previous work, ideological awareness materials covered three topics over three lecture periods: (1) "The Ugly Truth: Unethical Experimentation and its Relation to Human Rights Evolution," (2) "Intersection of Science and Identity," and (3) "Representation in STEM" (see Beatty et al., 2021 for further details). Subsequently, AEB, EG, CJB and others (see acknowledgements) expanded these topics into active learning activities (described in Table 1). AEB incorporated these expanded ideological awareness activities into the curriculum (Table 1), addressing the core benchmarks of the introductory biology curriculum over the course of a semester. Coauthor AEB made explicit connections between the biological core content and their societal impacts through the use of these activities.

The ideological awareness active learning lessons included representation in STEM, biological research ethics, integration of evolution and religion, genetics of gender and sexuality, environmental justice, healthcare disparities, and designer babies/genetic modification ethics. For example, in the biological research ethics topic, students learned about unethical experimentation in biology and medicine, including specific examples of unethical research studies. Students worked in groups to research and present on an unethical study. Additionally, students read "The Immortal Life of Henrietta Lacks" (Skloot), and at the end of the course participated in a debate on the legality of tissue ownership. For the representation in STEM module, students learned about representation in textbooks by reading a recent research article on the topic (Wood et al., 2020). They then analyzed textbooks to collect their own data about representation and discuss the results. In an additional activity, students created a profile of a scientist they selected, including the scientist's background, research, and why the student picked the individual to spotlight. For further details on all ideologically awareness activities, see Table 1 (expanded descriptions in Supplementary Table S1).

2.5. Student concept mapping

To determine whether exposure to ideological awareness activities increased students' ability to tie biological concepts to societal impacts, we asked students to create a concept map as part of their final exam. In both sections, the concept map was worth 20% of students' final exam. Concept maps consist of nodes containing specific concepts and links between the nodes representing relationships between concepts. Concept maps have been shown to be effective in increasing student knowledge retention, understanding relationships between topics within a course, and making connections between new and old knowledge (Novak, 1990; Van Zele et al., 2004; Nesbit and Adesope, 2006; Owens and Tanner, 2017). Concept maps have been used in biology education and other science disciplines to research student learning outcomes (Wallace and Mintzes, 1990; Dykstra et al., 1992; Esiobu and Soyibo, 1995; Pearsall et al., 1997; De Ries et al., 2022).

To account for instructor variance, coauthor AEB designed the concept map activity and introduced it to both sections. Subsequently, each instructor (authors AEB and PR) posted the concept map assignment to their online teaching platform, Blackboard, which consisted of a PDF instruction set (Supplementary File S1). This PDF instruction set consisted of a set of resources that described the proper methodologies for constructing a concept map. This included video tutorials, literature on the benefits of concept mapping, and references for concept map producing software. On the second page of the PDF,

TABLE 1 List of IA topics and activities implemented in the ideologically aware section.

IA topics	Descriptions of active learning activities
Representation in STEM	Students read select portions of Wood et al. (2020) dissecting representation within introductory science textbooks. Students scanned textbooks for graphic depictions of scientists, analyzed the themes, drew predictive graphs, and then compared the results from the peer-reviewed article to their own predictions. Additionally, students created scientist spotlights of a selected role model including the scientists' background, research, and why they picked this scientist to spotlight.
Biological research ethics	Students learned about unethical experimentation in biology and medicine. Students worked in groups to research and present on an assigned unethical study. This was then followed by a discussion of the ethical violations, how society responded, and what current rules would prevent these experiments from happening, including an explanation of the Belmont Report and the ethical framework that led to the development of the Institutional Review Board (IRB).
Henrietta Lacks	Students read "The Immortal Life of Henrietta Lacks" by Skloot (2010) throughout the course. At the end of the semester, they debated the legality of tissue ownership, drawing from the lesson on biological research ethics and the story of Henrietta Lacks.
Integration of evolution and religion	The instructor presented a brief lecture defining cultural competency and evolution. Students were then asked to discuss the prompt: "is evolution controversial?" Students were then shown quotes from religious leaders and evolutionary biologists of faith and discuss the coexistence of science and religion.
Genetics of gender and sexuality	Students read articles and chapters written by biologists related to organisms' sex and sex determination processes and learned the appropriate terminology for discussing sex and gender. Students then reflected and discussed the topic of the interaction of societal norms and science.
Environmental justice	Students discussed the basic principles of pollution, exposure to chemicals, and air pollution. Students predicted pollution and emissions across the United States and compared it with data collected from the Center for Disease Control. They discussed how we make decisions about pollution management as a society.
Healthcare disparities	Students learned about the healthcare disparities among people with historically excluded identities (racial, gender, and socioeconomic) by reading healthcare articles in groups and developing concept maps both individually and collaboratively.
Designer babies and genetic modification	Students received information about the latest gene editing technology including CRISPR-Cas9. Students then discussed/debated hypothetical pre-natal gene editing cases in small groups and answered a series of discussion questions.

Expanded descriptions in Supplementary Table S1. Full activities and annotated lectures available at https://tinyurl.com/IdeologicalAwareness.

the prompt for the concept map was followed by a set of "tips and tricks" for creating effective concept maps, the grading procedure, and examples of published concept maps. Students were given 1 week to complete the concept map and submit an electronic version for evaluation on BlackBoard.

The prompt for the final concept map is as follows:

> Create a concept map to describe the relationship between the core biology principles taught in this class (i.e. ecology, evolution, genetics, etc.) and their interconnectivities. Tap into the interdisciplinary nature of science by creating connections within the map to display the relationship between science and society. This should be a depiction of all you've learned this semester. Make sure you represent each biological concept fully. The number of connections and topics you have should reflect your knowledge. The amount of stuff you have written tells me how much you learned. To do this properly, we expect it will take you multiple hours.

Additionally, the PDF included a "tips and tricks section" with more detailed instructions. The fourth bullet specifically mentioned the societal content:

> Add in any connections you can make with society. Think about your everyday life and what is going on around you. In what ways do the core biological concepts taught in class related to those societal topics. One example may be the relationships between viruses and vaccines, but be sure to include enough detail to describe that relationship within the concept map.

2.6. Data coding

After students completed their concept maps, it was apparent that many students created lists of concepts, rather than complex webs mirroring the complex relationships between a variety of biological and societal concepts (example of student concept map in Figure 1). Due to this, we analyzed only the number and content and of the nodes in the maps, abandoning initial plans to analyze the concept maps for the density of connections between biology and societal concepts.

To begin our analysis of the concept map nodes, author EG used deductive coding (i.e., creating themes *a priori* rather than creating themes from the data; Saldaña, 2021) to create a coding rubric for the nodes in the concept maps. The two themes were "Society" and "Biology" (Figure 2). The "Society" theme includes content from the ideological awareness curriculum or other societal issues not traditionally focused on in biology curriculum, while the "Biology" theme includes content similar to the textbook or regularly included in a biology curriculum. EG took extensive, detailed analytic notes at that time (Birks and Mills, 2015). If a node did not fit intuitively into a theme, then EG discussed that node with AEB and CJB during weekly meetings, and they would come to consensus. After EG was finished coding, two undergraduate researchers used the codebook

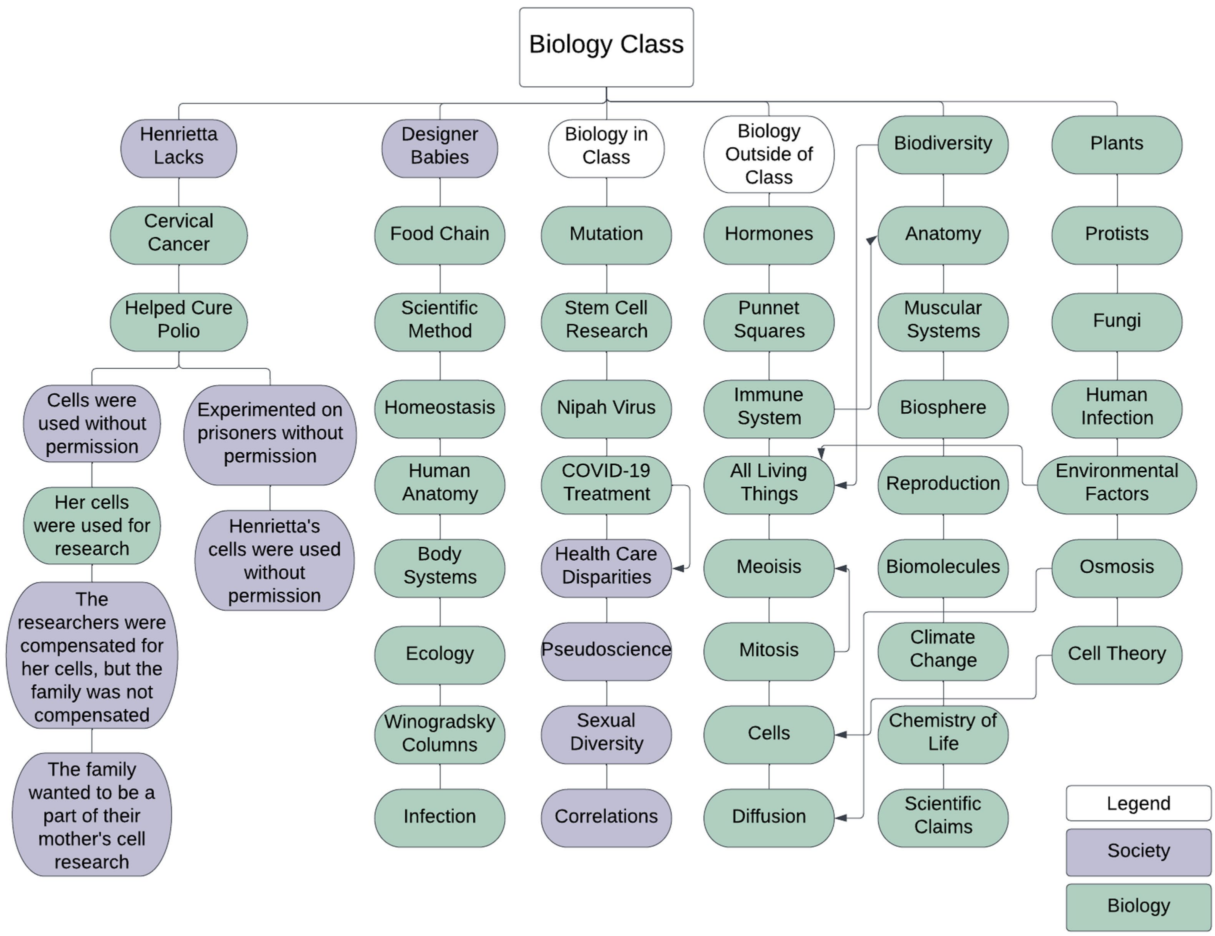

FIGURE 1
An example of a coded student concept map, modified for clarity and privacy. Biology nodes are coded in green and societal nodes are coded in purple. Nodes left white were excluded from our analysis.

she created (Figure 2) to code the same nodes as either society or biology. After the undergraduate students were finished coding their half of the maps, they switched maps to check each other's work. If one of the undergraduate students disagreed with the other undergraduate student's original decision, then they checked EG's decision and used this as a tiebreaker to make a final decision on all nodes in each concept map.

After the three coders coded all maps, coauthors PEA and EPD went through all maps and checked that they agreed with the decision made for each node in all concept maps. To change the theme of a node, both PEA and EPD had to agree on a different designation for the node, reaching consensus. For example, nodes that were illegible or considered off-topic were excluded (e.g., course and unit titles such as "BIOL 1000" and labels such as "in class"). PEA and EPD changed a small number of nodes (i.e., less than 5%) from one theme to another (e.g., "evolution" and "evolutionary theory" were originally coded as "Society" due to the "Integration of Evolution and Religion" lesson, but were changed to "Biology" because evolution is included in the textbook and traditional biology curriculum). After all nodes were coded, PEA and EPD entered the number of biology and societal nodes for each student's concept map into an excel spreadsheet. We then used this spreadsheet to conduct statistical analyses (see "Statistical and Descriptive Analyses" sub-section).

After we coded all nodes from the maps, we extracted all text from the societal nodes and pasted it into an excel document for further analysis. Coauthors PEA and EPD used deductive coding to create a coding rubric for the societal nodes. We created codes from the ideological awareness topics taught in the ideologically aware section (Figure 2). Additionally, we added a code to represent the societal nodes that did not fit an ideological awareness topic: "not aligned with an ideological awareness topic." After creating the codebook, PEA and EPD read through each of the societal nodes individually and coded them into the appropriate ideological awareness topic sub-code. Then, PEA and EPD convened, coming to an initial percent agreement of 81%. Through discussion, they came to consensus on each societal node code.

Finally, PEA and EPD further coded nodes within the "not aligned with an Ideological Awareness (IA) topic" code into one of five sub-codes using inductive coding (i.e., they created codes from data rather than creating codes *a priori*; Saldaña, 2021). The sub-codes were: (1) societal factors affecting science, (2) public science experience, (3) problems in science, (4) faulty information about science, and (5) distrust in science (Figure 3).

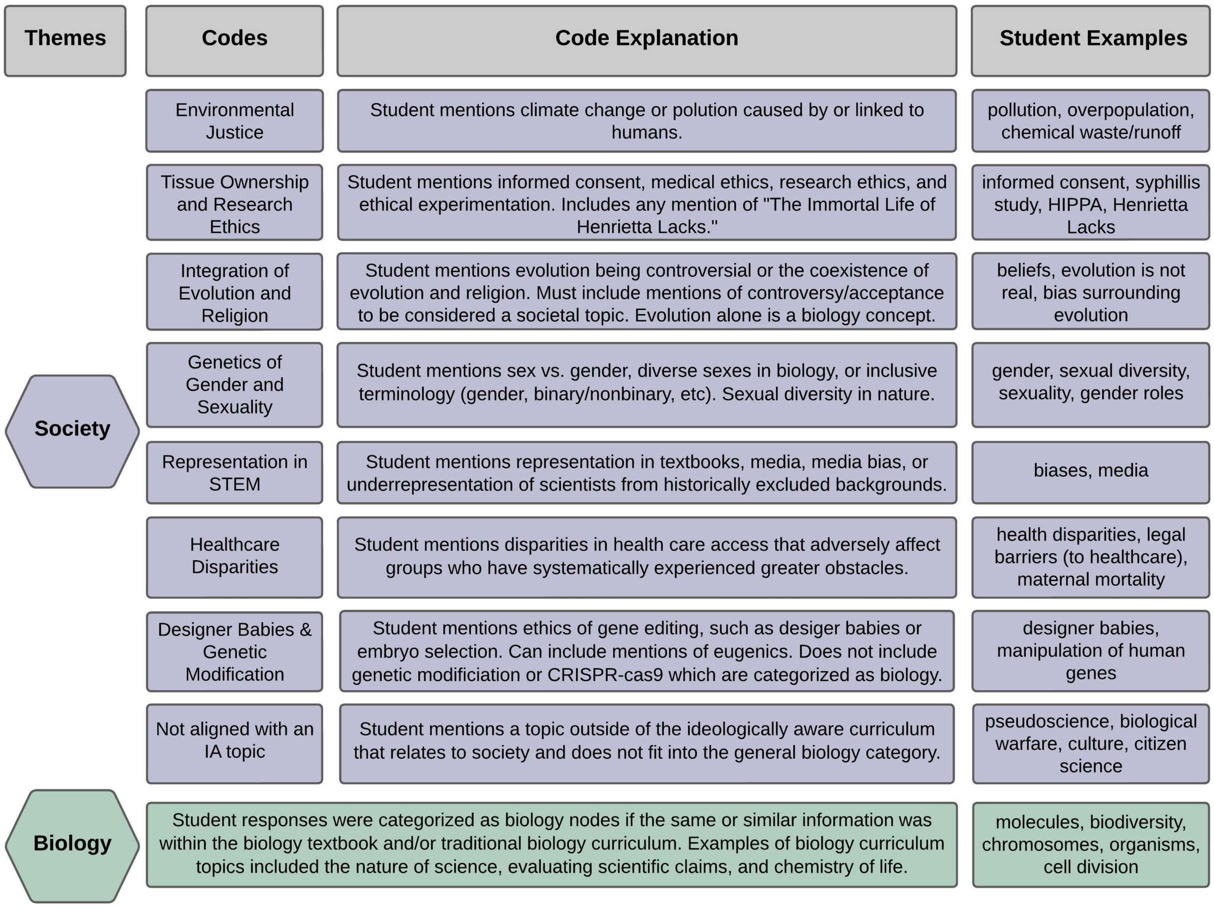

FIGURE 2
Explanation for qualitative codes of biology and society nodes with examples from student concept maps. We do not expand on or categorize the biology nodes because they were not a focus of the current study.

2.7. Statistical and descriptive analyses

To answer the first research question (i.e., Does exposure to ideological awareness materials increase the amount of biological and/or societal content mentioned in student concept maps, compared to students who were not exposed to ideological awareness materials?), we first analyzed counts of biological nodes per student by section (StudentBiologyNodes~Section), followed by the count of society nodes per student by section (StudentSocietyNodes~Section) with the lm linear model function in R Studio Team (2020) (see Table 2), with the nodes as the dependent variable and the section as the independent variable. No random effects were introduced for these models.

To address the second research question (i.e., what societal topics were students most likely to mention in each section? in the ideologically aware section and the traditional section?), PEA and EPD used qualitative content analysis (i.e., a tool used to determine the presence and frequency of certain codes within the open-ended responses; Morgan, 1993) to analyze the codes within the "Society" theme. We described the percent of students from each section that mentioned each of the ideological awareness topics as well as the percent of students from each section that mentioned societal nodes that did not align with an ideological awareness topic (topics shown in Figure 2). We compared the number of students who mentioned each topic to the total number of students per section as a percentage; these percentages therefore do not equal 100% as each student may mention multiple topics and be represented in more than one topic. We analyzed the number of distinct ideological awareness topics each student mentioned per section (StudentNumTopics~Section) using the lm linear model function in R Studio Team (2020) with the number of distinct topics per student as the dependent variable and the section as the independent variable without random effects (see Table 2).

Additionally, we were interested in students' own perceptions of how society and biology intersect. To investigate this question, PEA and EPD described the percentage of student concept maps that mentioned each sub-code of non-ideological awareness topics (totaling to the percentage of students who mentioned topics "not aligned with an ideological awareness topic"). We represented the presence and frequency of certain codes using qualitative content analysis (i.e., a tool used to determine the presence and frequency of certain codes within the open-ended responses; Morgan, 1993). Again, this was represented as the percentage of students in a section who mentioned a specific topic, and therefore the percentages do not total to 100%.

2.8. Student performance outcomes

Since the grading schemes were different for each section, we did not directly compare grades; however, we do provide the final average

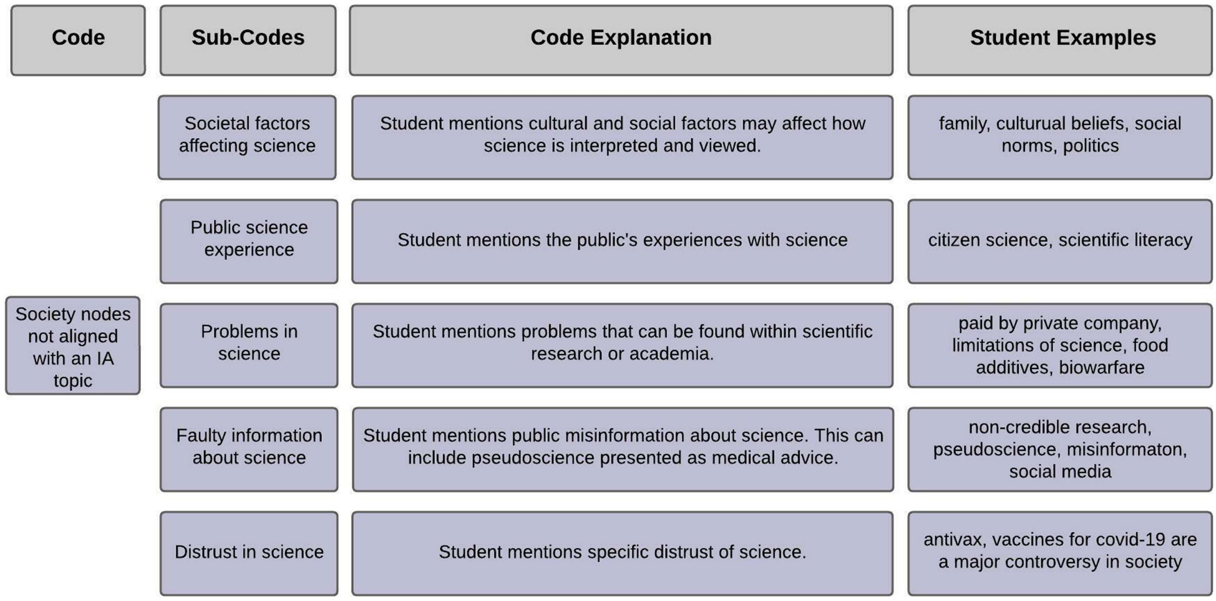

FIGURE 3
Explanation for qualitative codes of society nodes not aligned with an ideologically awareness topic with examples of nodes from student concept maps.

grade and standard deviation for each section, both for students who participated in the study and then for all students in the course. We used Excel to calculate the averages (i.e., means) and standard deviations for both sections. We used stdev.s to calculate standard deviations for the consenting students in each section, and we used stdev.p to calculate standard deviations for all students enrolled in each section.

3. Results

3.1. Amount of biological and societal content mentioned by students

First, we addressed the research question: *Does exposure to ideological awareness materials increase the amount of biological and/or societal content mentioned in student concept maps, compared to students who were not exposed to ideological awareness materials?* To address this question, we used individual linear models to analyze the independent variables of biology node count and societal node count by section (Table 2). More specifically, the ideologically aware section listed 20.53 (± 41.13; 95% CI) fewer mean biology nodes than the traditional section; this was not statistically significant ($p = 0.32$, df = 34) (Figures 4A,C). However, the ideologically aware section listed significantly more societal nodes than the traditional section (5.55 [± 3.82; 95% CI] $p = 0.0057$, df = 34) (Figures 4B,D).

3.2. Societal topics mentioned by students

Second, we addressed the first part of the second research question: *What societal topics were students most likely to mention in the ideologically aware section and the traditional section?* To address this question, we coded society node responses from the concept maps by ideological awareness topic (see Table 1 for ideological awareness topics; Figures 2, 3 for code explanations). This process allowed us to tie these nodes back to the ideological awareness topics taught in the ideologically aware section. We then analyzed the number of distinct ideological awareness topics mentioned by each student in their concept map. This allowed us to control for variation in student concept maps by topic. For instance, one students' concept map was 75% societal nodes (22 of 29 nodes) but only covered 2 unique topics, while another students' concept map contained 12% societal nodes (6

TABLE 2 Research methods used to answer each research question.

Research question	Method used to answer question
Does exposure to ideological awareness materials increase the amount of biological and/or societal content mentioned in student concept maps, compared to students who were not exposed to ideological awareness materials?	Qualitative coding • Nodes coded as 'biology' or 'society' Linear model (lm) analyzing counts • Biology nodes (per student) by section • Societal nodes (per student) section
What societal topics were students most likely to mention in the ideologically aware section and the traditional section?	Qualitative coding • Societal nodes coded by Ideologically aware topics • Societal nodes that did not fall into an ideologically aware topic were coded into one of five sub-categories Linear model (lm) analyzing number of topics • Unique societal topics (per student) by section

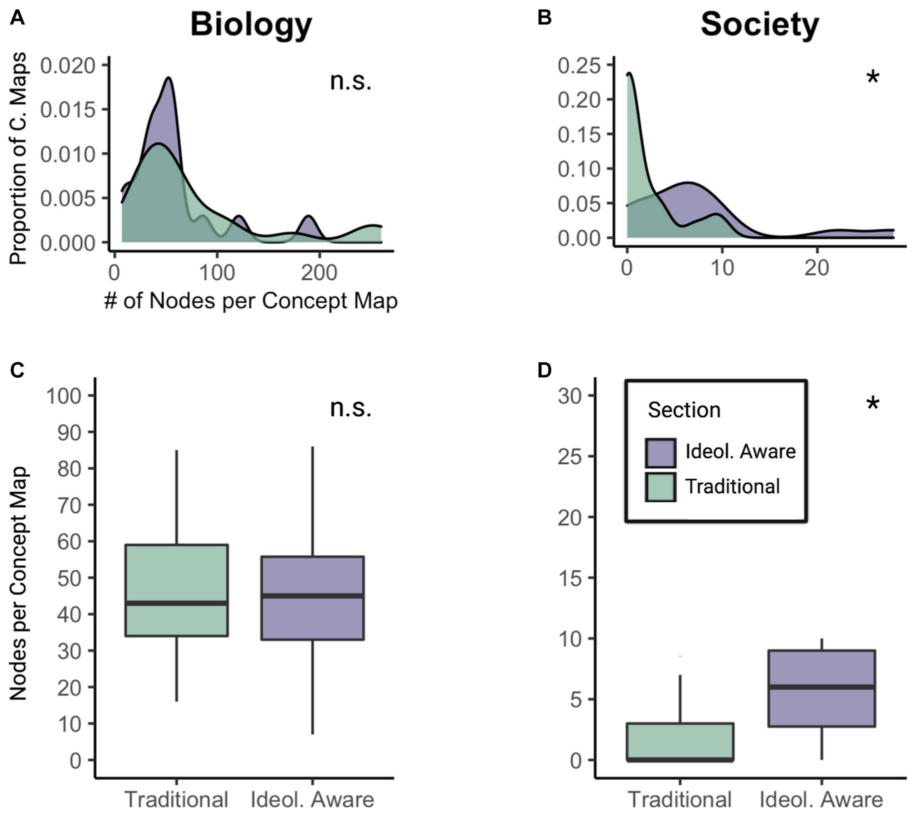

FIGURE 4
Counts of coded nodes as presented by the number of biology nodes per student per section and the number of society nodes per student per section. **(A,B)** are density plots showing the distribution of node counts per concept map per section. **(A)** Number of biology nodes per section and **(B)** Number of society nodes per section. **(C,D)** are boxplots showing the distribution of node counts per concept map per section. **(C)** Number of biology nodes per section and **(D)** Number of society nodes per section. Statistical significance is based on $p < 0.05$ and is denoted by an asterisk (*). n.s. means "not significant".

of 57 nodes), but included 5 unique topics. Findings showed that students in the ideologically aware section mentioned an average of 2.81 societal topics, which was 1.96 (± 1.10; ± 95%CI) more topics than students in the traditional section who mentioned less than one topic (0.85) on average ($p < 0.001$, df = 24) (Figure 5).

Delving into the specifics about which topics were mentioned by the ideologically aware section, the most common topic mentioned was "tissue ownership and biological ethics," with 69% of students in that section mentioning it at least once in their concept map (Figure 6A). This topic included any mentions of *The Immortal Life of Henrietta Lacks* reading assignment, a book they read throughout the semester (Skloot, 2010), and these mentions dominated this section with 62.96% of the "tissue ownership and biological ethics" nodes referring to content from the book. However, other mentions in this code referenced the United States Public Health Service Syphilis Study at Tuskegee and included "informed consent," "HIPAA," "experimented on prisoners without permission," "ethics," and the "syphilis study." The second most common topic mentioned by the ideologically aware section was "genetics of gender and sexuality," with 56% of students mentioning it at least once on their concept map (Figure 6A). The third most common code from the ideologically aware section is "not aligned with an IA topic," with 50% of students mentioning at least one societal node that did not fit into an ideological awareness topic. Less mentioned ideological awareness topics by the ideologically aware section included: "healthcare disparities" (44%), "designer babies" (38%), "representation in STEM" (13%), "integration of evolution and religion" (6%), and environmental justice" (6%; Figure 6A).

In the traditional curriculum, the majority of concept maps (55%) had no mentions of societal topics (Figure 6). When students in the traditional section did mention society in their concept maps, these mentions were typically not aligned with an ideological awareness topic (35%) (Figure 6A). When the societal nodes mentioned by the traditional students did align with an ideological awareness topic, the most common mentions were "representation in STEM" and "integration of evolution and religion" with 15% of students mentioning each topic (Figure 6A). Less commonly mentioned ideological awareness topics by the traditional section included "environmental justice" (10%), "tissue ownership and biological ethics" (5%), and "designer babies" (5%) (Figure 6A). Two of the ideological awareness topics were never mentioned by any of the traditional students: "genetics of gender and sexuality" and "healthcare disparities" (Figure 6A).

In comparing the two sections, more students in the ideologically aware section mentioned societal topics that were both aligned and unaligned with ideological awareness topics. Specifically, 50% of students in the ideologically aware section mentioned societal topics that did not align with ideological

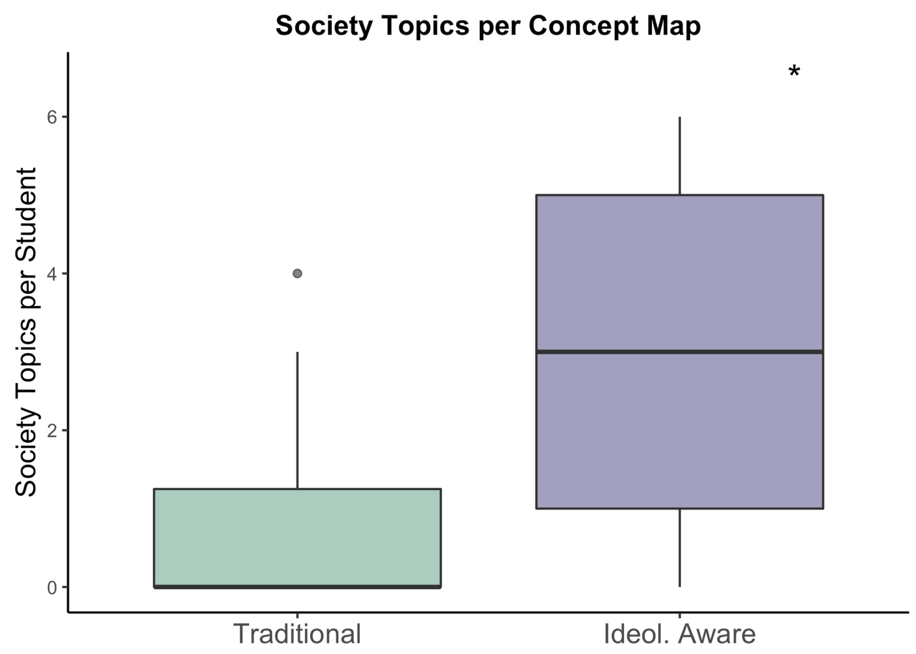

FIGURE 5
Distribution of total unique society-related topics mentioned per student in each section presented as a boxplot. Statistical significance is based on $p < 0.05$ and is denoted by an asterisk (*).

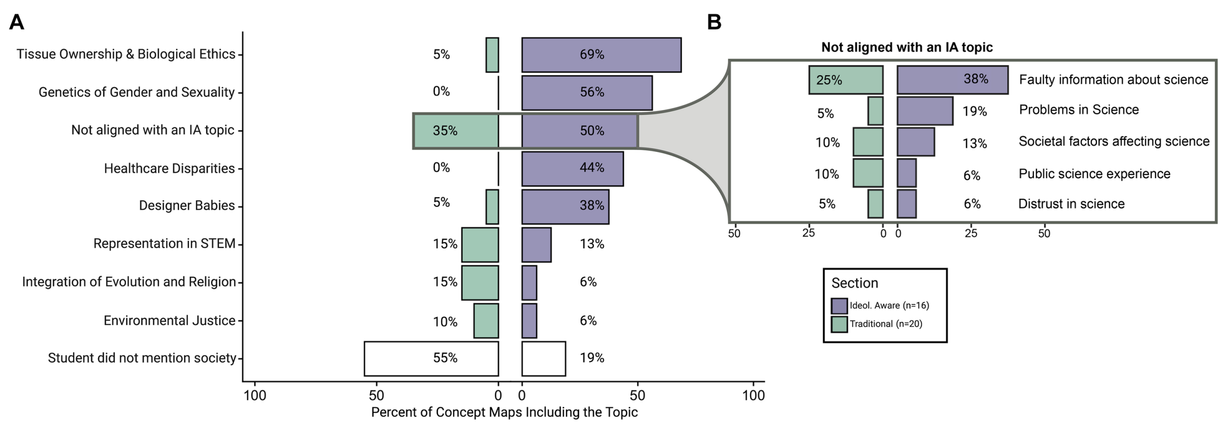

FIGURE 6
Percent of student concept maps mentioning a topic. The data is presented by section, with the ideologically aware section in purple (right) and the traditional section in green (left). The data is presented only as descriptive because the sample size was too small to test for statistical significance. Additionally, topics did not add to 100% because each concept map may have mentioned multiple topics and therefore be represented multiple times. **(A)** Percentage of student concept maps that (1) mentioned at least one of the seven ideological awareness topics, (2) did not align with an ideological awareness topic, or (3) did not have any societal nodes (shown in white). **(B)** Percentage of concept maps that mentioned a societal topic that did not align with one of our prescribed ideologically aware codes.

awareness curriculum compared to the 35% of students in the traditional section who did the same.

3.3. Societal topics outside of the ideological awareness curriculum

Third, we further addressed the second research question: *What societal topics were students most likely to mention in the ideologically aware section and the traditional section?* To do this, we analyzed the code of societal nodes that did not align with any of the ideological awareness curriculum topics by creating sub-codes for those societal topics (examples in Figure 3). The most common sub-code for those nodes that did not align with an ideological awareness topic was "Faulty information about science" (38% of concept maps in the ideologically aware section and 25% of concept maps in the traditional section). In the ideologically aware section this was followed by "Problems in science" (19% of concept maps) with few mentions of the other sub-codes [i.e., "societal factors affecting science" (13%), "public science experience" (6%), and "distrust in science" (6%)] in both sections (Figure 6B).

3.4. Student performance outcomes

Due to differences in the grading structure of each section, we did not compare performance outcomes between sections. However, for transparency, we report the final grades for the students who participated in the study as well as the full course final average. The final grade average for students who participated in the study was 86.82% (SD = 13.22%) in the ideologically aware section and 91.76% (SD = 8.81%) in the traditional section. For comparison, the final grade average for all students in the ideologically aware section was 79.14% (SD = 20.17%) and 84.72% (SD = 18.59%) in the traditional section.

4. Discussion

We found that students included more societal content to their concept maps in the ideologically aware section than the traditional biology curriculum. The additions of societal content did not come at the expense of the biological content coverage in the concept maps; students in both sections included the same amount of biological content. The makeup of societal content differed by class section. Students in the ideologically aware sections most commonly mentioned the ideological awareness topics of (1) tissue ownership and biological ethics and (2) genetics of gender and sexuality. These students also included additional societal content that was not aligned with an ideological awareness topic taught by the instructor. In the traditional sectional, however, students rarely mentioned societal topics that were aligned with an ideological awareness topic, but when they did, the most common topics were (1) representation in STEM, (2) integration of evolution and religion, and (3) environmental justice. Of the responses mentioned by students in both sections that were not aligned with ideological awareness topics, the most common sub-codes were (1) "faulty information about science" (e.g., non-credible research, pseudoscience), (2) "societal factors affecting science" (e.g., family, cultural beliefs, social norms) and (3) "problems in science" (e.g., research was paid for by a private company, biowarfare) (Figure 3). Here, we discuss these main findings and place them in the context of previous literature. Subsequently, we provide resources and encouragement to instructors interested in implementing ideological awareness active learning materials in their biology classrooms.

4.1. Finding 1: students included more societal content in the ideologically aware class section without taking away from their biology content knowledge

Integrating science and society in the classroom does not have to decrease the amount of biology content student learn. We found that there was no difference between the two sections with respect to the number or proportion of biological content included on the concept maps (Figure 4). One common instructor hesitancy to integrating societal content into the biology curriculum is that it will come at the expense of students' content knowledge (Levinson, 2006; Sadler et al., 2006; Herman et al., 2017; Tidemand and Nielsen, 2017; Beatty et al., 2023). However, our results show that while the ideologically aware class section learned more societal topics in biology, this did not come at the expense of biology content knowledge gained through the semester. Future work will address this question more rigorously, as a limitation of the current research is the use of node counts as a proxy for knowledge.

The ability of our ideologically aware section students to mention society more frequently than the traditional section demonstrates students often do not understand the relationship between science and society unless their instructors make those explicit connections for them. In fact, previous research demonstrated that without relatable connections to society, students struggled to contextualize scientific facts (Gilbert, 2006; Chamany et al., 2008; Hofstein et al., 2011). Additionally, integrating societal content can make science courses more relevant to students (Osborne and Collins, 2001; Holbrook, 2005; Chamany et al., 2008; Hofstein et al., 2011), and students are often more enthusiastic about science when they find the content relevant (Hewitt et al., 2019). Both our findings and those from previous research show that biology students benefit from instructors who contextualize biology within societal contexts.

The ability of students in the ideologically aware section to include more societal topics in their concept maps may have been influenced by the instructional format used in that section (i.e., a flipped classroom format). The flipped classroom used active learning to deliver societal content, and a robust amount of literature has demonstrated that students perform as well, if not better when exposed to these interactive pedagogies (Walker et al., 2008; Haak et al., 2011; Freeman et al., 2014; Heyborne and Perrett, 2016; Gavassa et al., 2019; Strelan et al., 2020). Therefore, the success of the ideological awareness curriculum used in our study could be due to the curriculum, the active learning format in which it was taught, or a combination. However, traditional course content rarely makes the explicit connections to society made by our ideologically aware curriculum (Tanner and Allen, 2007; Nielsen, 2020; Beatty et al., 2023), and students are often unable to make connections between science and society without explicit instruction (Hofstein et al., 2011).

4.2. Finding 2: students most commonly included the following two ideological awareness topics: (1) Tissue ownership and biological ethics and (2) gender and sexuality

4.2.1. Tissue ownership and biological ethics

The most commonly included societal topic by students in the ideologically aware section was tissue ownership and biological ethics related to *The Immortal Life of Henrietta Lacks* (Skloot, 2010) and discussion of historical unethical research experiments (for more information about student activities see Table 1). With the emphasis on the story of Henreitta Lacks, 62.96% of nodes about biological ethics referred to Henrietta Lacks in the ideologically aware section. Our findings echo previous research, where students reported that they prefer *The Immortal Life of Henrietta Lacks* to a traditional textbook, finding it more useful, engaging, and relevant to teaching about societal issues (Beatty et al., 2021). Teaching biological research ethics has been shown to increase students critical thinking (Gunn et al., 2008; Chowning et al., 2012) and bioethical decision making (Gutierez, 2015). Previous research teaching biomedical research ethics using socio-scientific issues demonstrated increased student understanding of science and society (Chowning et al., 2012). Content from *The Immortal Life of Henrietta Lacks* gives rise to conversations about informed consent and healthcare inequalities (Nisbet and Fahy, 2013; Sodeke and Powell, 2019). This book and the story of Henrietta Lacks have been used in other course-based and group learning activities to expand student knowledge beyond traditional education into a more nuanced discussion about the history of African Americans in medical research (Virtue et al., 2018; Baptiste et al., 2022), professional roles, responsibility and advocacy (Hunt et al., 2020), and deeper discussions about socioeconomic and healthcare disparities in the United States (Dimaano and Spigner, 2017; Virtue et al., 2018).

4.2.2. Genetics of gender and sexuality

Students in the ideologically aware section emphasized materials related "genetics of gender and sexuality" in their concept maps (Figure 6). The "genetics of gender and sexuality" lesson may have been of particular interest to students due to the contemporary relevance of the Lesbian, Gay, Bisexual, Transgender, and Queer (LGBTQ) communities in media and politics. For example, the years 2021 and 2022 have both held record setting numbers of anti-LGBTQ legislation measures (American Civil Liberties Union, 2023), but 2022 ended with the enaction of the Respect for Marriage Act which protects the right of "same-sex (and interracial)" marriages (Megerian, 2022). With the increase in political and media attention, 70% of LGBTQ Americans reported personally experiencing discrimination in 2022 (up 24% from 2020; GLAAD, 2022). Simultaneously, higher percentages of individuals aged 18–34 report identifying as LGBTQ or as allies than other age groups (GLAAD, 2017; Jones, 2021). Despite the increasing visibility, prevalence, and relatability of topics relating to gender and sexuality, students in the traditional section did not mention gender or sexuality in their concept maps, again indicating that without explicit instruction students do not think these topics are related to biology.

Our ideological awareness curriculum explicitly addressed the inaccuracy of cisnormative terminology to describe sexual systems in nature, in comparison to traditional biology curriculum that often relies on the idea of biology as a 'neutral' space that may unintentionally rely on gender essentialism or the gender binary for the sake of simplicity (Baeckens et al., 2020; Casper et al., 2022; Zemenick et al., 2022). This problematic 'neutral' framing of sex in biology classrooms can directly harm transgender and gender-nonconforming students, who have reported a decreased sense of belonging and a decreased interest in the content and discipline (Casper et al., 2022). The result is that transgender and gender-nonconforming students are underrepresented in biology (Maloy et al., 2022). However, these same students identified the potential power that biology education could have to validate queer orientation and gender (Casper et al., 2022). Recent work calls to move beyond gender essentialism by centering biological diversity and use inclusive language in the biology curriculum (Casper et al., 2022; Zemenick et al., 2022). In our work, we show that students who received the ideological awareness curriculum often mentioned the genetics of gender and sexuality information they learned.

4.3. Finding 3: in the absence of ideological awareness curriculum, students focused on pseudoscience and misinformation

Students also mentioned content unrelated to the ideological awareness curriculum in their concept maps. In fact, these nodes were the third most common societal topic group in the ideologically aware class section, and the most common societal topic in the traditional section (50 and 35% of concept maps respectively; Figure 6A). When we categorized the responses within this group, we found the most common code was "faulty information about science," with 38% of students in the ideologically aware section and 25% of students in the traditional section including it in their concept maps (Figure 6B). Examples of "faulty information about science" included mentions of social media, which has been shown to increase the spread of misinformation (Brossard, 2013; Vosoughi et al., 2018). One student from the traditional section specifically mentioned health misinformation in their concept map that was spread by the Dutch daredevil Wim Hoff, a social media influencer. Together, these mentions of pseudoscience and social media likely were inspired by the required textbook for the course, as both sections of the course began with content from "Chapter 2: Evaluating Scientific Claims," which included topics such as reliability of sources and pseudoscience (Houtman et al., 2020). This is further evidence that students looked to resources such as their textbook and their lessons in class to make connections between science and society.

Including socially relevant topics in biology curriculum may be an effective strategy to combat the growing concern in the scientific community about the spread of misinformation and pseudoscience in the media in recent years—now dubbed the "post-truth" phenomenon (Hansson, 2017; Mcintyre, 2018; Scheufele and Krause, 2019; Barzilai and Chinn, 2020). Post-truth refers to a "range of current threats to people's abilities to know what is true or most accurate in media-and information-rich societies" (Barzilai and Chinn, 2020). Misinformation and pseudoscience have affected science literacy across many parts of science from health and medicine (Wenzel, 2017; Chou et al., 2018; Callaghan, 2019), climate science (Zummo et al., 2021; Hufnagel, 2022), race and ethnicity (Graves Jr, 2002; Donovan et al., 2021a, 2021b; Chialvo, 2023), and the COVID-19 pandemic (Brennen et al., 2020; Zarocostas, 2020; Islam et al., 2021). While this present study did not investigate the effect of teaching the bidirectional impacts of science and society on student alternate conceptions concerning science, this is an important future avenue to explore.

4.4. Resources for instructors

Teaching science to all students by emphasizing the bidirectional impacts of science and society is important, but previous research demonstrated that instructors may be hesitant to teach these impacts due to lack of resources (Beatty et al., 2023). For this reason, we provide the ideological awareness materials used in the present study.[1] Additionally, we provide a list of other resources in Table 3, organized by the ideological awareness topics used in the present study.

1 Access them here: https://github.com/aeb0084/Ideological-Awareness-Activities.

TABLE 3 A list of resources for instructors who are interested in implementing an ideological awareness activity in their classroom.

Topic	Resources for instructors
Ideological awareness	To access the ideological awareness activities discussed in this study check out our GitHub page: https://github.com/aeb0084/Ideological-Awareness-Activities
Representation in STEM	a. To show students that scientists come from a diverse range of backgrounds, check out: https://500queerscientists.com/; https://projectbiodiversify.org/; and https://scientistspotlights.org/
	b. To integrate worksheets with real data from scientists from diverse backgrounds, check out: https://datanuggets.org/dataversify/
	c. To learn more about the underrepresentation of scientists from diverse backgrounds in textbooks, see Wood et al. (2020). For a more comprehensive list of resources for students that relate to increasing diversity and fostering discussions on inequity in science, see Simpson et al. (2021).
Biological research ethics	a. For an overview of the development of bioethics, see: https://www.ncbi.nlm.nih.gov/books/NBK543570/
	b. To access and read The Belmont Report, the ethical principles and guidelines for the protection of human subjects of research, see: https://www.hhs.gov/ohrp/regulations-and-policy/belmont-report/read-the-belmont-report/index.html
	c. For history of unethical research performed on African Americans, read Baptiste et al. (2022). For a review of unethical medicine more generally, read Lederer (2009).
	d. Tuskegee University has a center committed to bioethics, which can be found here: https://www.tuskegee.edu/about-us/centers-of-excellence/bioethics-center
Integration of evolution and religion	a. To learn about the landscape of evolution education and acceptance among specific student identity groups, read Dunk et al. (2019) and Barnes et al. (2020), respectively.
	b. To learn about interventions that may have a positive effect on student acceptance of evolution, see Truong et al. (2018).
	c. For resources designed to demonstrate religion and science can be compatible, see: https://www.theclergyletterproject.org/
Genetics of gender and sexuality	a. For resources on how to adapt curriculum to be more gender-inclusive, see Gender-Inclusive Biology: https://www.genderinclusivebiology.com/
	b. For recommendations on creating a more inclusive environment for LGBTQ+ individuals and embracing gender and sexual diversity in post-secondary biology see Casper et al. (2022), Cooper et al. (2020), and Zemenick et al. (2022).
Environmental justice	a. For a review of literature on environmental justice in industrially contaminated sites in Europe, see Pasetto et al. (2019).
	b. For studies confirming a correlation between the location of hazardous waste treatment, storage, and disposal facilities and race and ethnicity in the United States, see Boer et al. (1997), Pollock Iii and Vittas (1995), and Ringquist (1997).
	c. For studies linking persons living near benzene waste sites to hematological cancers, see Boberg et al. (2011) and Gensburg et al. (2009).
Healthcare disparities	a. For information on health care disparities in SARS-CoV-2 testing sites, read Rader et al. (2020). For a review of mental health care disparities, read Cook et al. (2019).
	b. For studies on interventions attempting to reduce health care disparities, see Myers (2019) and Lee et al. (2019).
Designer babies and genetic modification	a. For resources to bring discussions of human genome editing into your classroom, see: https://www.geneticsandsociety.org/internal-content/cgs-teaching-resources and https://www.bio-rad.com/en-us/applications-technologies/crispr-cas-gene-editing-teaching-resources?ID=Q58I0DWDLBV5
	b. For a review of CRISPR gene therapy, read Uddin et al. (2020).
Misinformation, pseudoscience, and scientific literacy	a. See Barzilai and Chinn (2020) for a review of educational responses to the "post-truth" condition.
	b. For suggestions on improving scientific and media literacy see Reid and Norris (2016) and Höttecke and Allchin (2020).
	c. See Feinstein et al. (2013) for ways to cultivate 'competent outsiders' as we reimagine biology education for non-scientists.

4.5. Limitations and future directions

The results of this study have limitations. First, we were unable to analyze the density of connections between nodes and quality of content within concept maps because there was considerable variation in how students constructed their concept maps. Despite both sections receiving information and instruction on how to make and complete their concept map, many students seemed to focus on making lists of nodes (see Figure 1), connecting them to more than one node infrequently and almost as an afterthought to meet the aims of the assignment. We rarely found complex webs mirroring the complex relationships between a variety of biological and societal concepts. For this reason, we analyzed the number of nodes per map to compare the difference in biology and society content in each section and did not analyze the density of connections. Previous work using concept maps to test the impact of learning interventions suggested instructors provide students with information and structure for their concept maps and allow students to revise their concept maps and the network of information within them (Reader and Hammond, 1994). In future studies, allowing students to receive feedback on their concept maps and then make appropriate revisions could foster the development of more dense networks between the content they learned in class. We could then use previously created rubrics to score concept maps for their "knowledge integration" (Besterfield-Sacre et al., 2004).

Improvements in the density of connections and quality of concept maps would allow for more advanced analyses of students' ability to make connections between science and society.

Second, the number of students in our study is small, and so we caution readers about the generalizability of our results. We created linear models to analyze the data for statistical differences with 16 students in the ideologically aware section and 20 students in the traditional section. According to the Central Limit Theorem (Ott and Longnecker, 2015, pgs. 185–189), each treatment group should have at least 30 data points (i.e., students in this case) and the data should be normally distributed. However, given that *p* values are based on sample size and effect size (Thiese et al., 2016), this likely demonstrates that the ideological awareness curriculum had a very large effect in our study. To confirm the repeatability of these findings though, and rule out the argument that our results are due to random or systematic error (Thiese et al., 2016), future experiments with larger numbers of students are necessary.

Third, we did not collect data on whether students with historically excluded identities had negative responses to the ideological awareness curriculum. This is important to evaluate because these students (e.g., those who could personally identify with aspects of focal individuals described in the ideological awareness curriculum) are at a greater risk of being tokenized (Gutiérrez y Muhs et al., 2012) and receive microaggressions in the classroom (Harrison and Tanner, 2018). Despite the limitation to the current work, previous research using an abridged version of the ideological awareness curriculum showed students who identified as a person excluded because of their ethnicity and race (PEER) reported equal or higher approval of the ideological awareness materials than non-PEER students (Beatty et al., 2021). However, it is important in future work to evaluate PEER students' perceptions of the extended version of this ideological awareness curriculum across different contexts and approaches to implementation. Additionally, given the inclusion of topics centering on LGBTQ issues (i.e., genetics of gender and sexuality and healthcare disparities) it is also important to evaluate LGBTQ students' perceptions of the extended version of this ideological awareness curriculum across different contexts and approaches to implementation.

Fourth, we were unable to definitively compare student achievement outcomes between sections due to differences in grading structure. In the traditional section, students were evaluated with four tests (65.57%), three quizzes (12.3%), in-class points (8.20%), and homework (13.93%). In the ideologically aware section, students' grades consisted of presentations (10%), written reflections (10%), homework and assignments (25%), participation (20%), quizzes (30%), and the concept map as a final exam (5%). The traditional section relied heavily on summative assessments (e.g., high stakes exams) in comparison to the ideological awareness section, which did not use high stakes exams and included more low-stakes assignments. In the future we should think more critically about the implementation of grading schemes to make comparisons of student performance outcomes between sections.

Finally, the extent of the impact of the active learning structure on our results is unclear. In the current study, we compared a 'value-free' biology curriculum with traditional lecture to an ideological awareness curriculum with active learning. However, we did not test an ideological awareness curriculum with traditional lecture to an ideological awareness curriculum with active learning. Future work will profit from a direct comparison of active learning and traditional lecture on students' ability to make connections between science and society with the same ideological awareness curriculum.

5. Conclusion

Biology courses need to make the coverage of biology engaging, current, and relevant to students' lives. Biology instructors have the enormous task of presenting students with how the living world came to be, how it continues to change, and the inextricable link between science and societal challenges. Fortunately, students will be more likely to take the effort to understand biological concepts when they can see the applications and relevance of content to their lived experiences. While this study is exploratory in nature, it provides solid evidence that ideological awareness increases the amount of societal content that students associate with biology.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation. Statistical and data visualization code can be found at https://github.com/peadams/IA-Concept-Maps. Full activities and annotated lectures available at https://tinyurl.com/IdeologicalAwareness.

Ethics statement

The studies involving human participants were reviewed and approved by the Auburn University Human Research Protection Program: Institutional Review Board for the Protection of Human Subjects in Research (IRB). The patients/participants provided their written informed consent to participate in this study.

Author contributions

CJB, AEB, and JAH contributed to the conception and design of the study. PR and AB collected the data. PEA, EPD, and EG coded the data. PEA and EPD performed the statistical analyses. PEA, EPD, and CJB wrote the manuscript. All authors contributed to the manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2023.1154609/full#supplementary-material

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