Evaluating Representation in Science Through a Peer-Reviewed Research Study

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Abstract

The demographic representation of scientists featured in biology curricular materials do not match that of the undergraduate biology student population or of the U.S. population. In this lesson, we promote awareness of inequity in science through an exercise that encourages students to think about who is depicted as scientists in science curricular materials—specifically, biology textbooks. After a brief lecture on the scientific method, students read an excerpt from the introduction of a peer-reviewed publication that provides background information on the importance of representation in science. Next, students collect data from their own biology textbook about the representation of scientists who possess different identities and make a table depicting their results. Then, students fill in predictive graphs about demographic representation over time with respect to scientist identities including perceived gender and race/ethnicity. Students compare their predictions with the results from the peer-reviewed article and discuss the implications of the results. Finally, students apply their new knowledge by designing an experiment that would examine representation of an alternative scientist identity, such as age. Students conclude by answering questions that gauge their knowledge of the scientific method. This activity uses a peer-reviewed publication as well as authentic data generated by the student to increase ideological awareness and teach societal influences on the process of science.

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Learning Goals

Students will:

◊ describe the process of the scientific method.

◊ read and interpret findings from a summary of a peer-reviewed publication.

◊ extract data from a biology textbook and produce a summary table.

◊ make predictions of demographic representation of scientists over time.

◊ design an experiment to test their predictions based on the conclusions of the article and their own observations.

Learning Objectives

Students will be able to:

◊ list the steps of the scientific method.

◊ apply the scientific method to create several novel research questions.

◊ articulate the implications of student exposure to primarily stereotypical (*i.e.,* white, masculine) scientist representation in biology textbooks.

◊ collect and analyze their own data and generate a summary table.

◊ produce observation-based predictions and compare them to peer-reviewed and published results.

◊ define ideological awareness and describe its impact on historical and contemporary science.

INTRODUCTION

Introductory biology textbooks expose students to the science of living organisms and the natural world while highlighting historical and contemporary scientists who make discoveries on the forefront of knowledge. Previous research that examined the intersectional identities of scientists across seven of the most commonly used biology textbooks in the United States found that the majority of featured scientists were white men (1). Intersectionality acknowledges how multiple dimensions of individuals' salient identities (*e.g.,* race, class, gender) intersect, resulting in compounded forms of inequality or discrimination (2, 3). Women and scientists of color (which the authors define as scientists who are not white) were dramatically less represented across textbooks. For example, across the approximately 164 scientists mentioned per textbook, the researchers did not observe a single example of a Black woman scientist (1).

The ability to "see oneself in science" impacts students' perceptions of who can do science. Exposing students to a diverse range of scientist role models increases the probability that students find similarity between themselves and scientists. Scientists in curricular materials contribute towards the implicit or hidden curriculum, or the subtextual messaging students observe in an achievement environment (such as the science classroom) which signals to some that they naturally belong there and can succeed (4). In curricular materials, student exposure to counterstereotypical scientists lead to significant shifts in students' relatability to scientists (5–7), perceptions of scientists (5–8), performance outcomes (7), and gains in science identity measures (6, 7). The stereotype inoculation model suggests these positive outcomes are the result of role models functioning as "social vaccines" who increase social belonging and inoculate fellow group members' self-concept against stereotypes (9). Given the benefits of scientist role models, and their absence in contemporary biology textbooks, curricular materials that urge students to ponder their impacts may enhance understanding of the inequalities present in science disciplines.

While we present one activity to promote student thinking about the lack of demographic diversity in biology textbooks, several resources exist to promote scientists with diverse identities (10). For example Project Biodiversify (11) provides slides that can be used in classroom teaching (12), while Scientist Spotlights are written reflection assignments authored primarily by undergraduates (13). 500 Women Scientists (14) and 500 Queer Scientists (15) feature biographical information that can be used in class lectures or activities.

This lesson encourages students to think about why it's important to have diverse representation of scientists in biology textbooks to foster students' understanding of the potential impact that biases and stereotypes have on science (Supporting File S1). This concept, called 'ideological awareness' (16), highlights how dominant ideologies and paradigms shape our knowledge of biology and the application of that knowledge (17). In this activity, we apply an ideological awareness framing through discussions of (1) the historical and contemporary exclusion of certain groups from science and (2) the portrayal of science as exceptional and exclusionary. Ultimately, this activity invites students to question, challenge, and critique structural inequalities in science, rather than treat biology as a 'value-free' discipline.

Intended Audience

This activity was designed for lower-level biology courses for majors as well as STEM or pre-health majors at a large public research university in the Southeastern United States. It was also delivered to lower-level biology courses for majors as well as STEM or pre-health majors at a smaller, public regional institution in the Southeastern and Northeastern parts of the United States. The slide deck starts by describing the process of science, which may be most suitable for first-year or lower-division students. Then, students engage in an activity aimed to promote ideological awareness, which would be suitable for any undergraduate across lower-division or upper-division coursework (16). For more advanced audiences, instructors can emphasize the use of these sorts of data in a predictive manner to inform policy.

Required Learning Time

The required time to complete this activity is approximately 75 minutes. However, this may vary depending on the classroom because of the inclusion of primary literature, several open-ended questions, and opportunities for discussion.

Prerequisite Student Knowledge

Students are not required to have any disciplinary biology knowledge prior to completing this lesson. However, before any lesson that involves sensitive topics, such as representation in STEM or structural inequalities, we recommend instructors create a space for respectful and reflective conversation and group discussions (see *Inclusive Teaching* section below; an acknowledgement of the paper's limitations in *Textbook Data Collection* section; and the *Reflection* section).

Prerequisite Teacher Knowledge

We recommend instructors are familiar with Wood *et al.* (1), the featured publication in the activity, and seek out statistics about the underrepresentation of identities across the scientific workforce. The National Center for Science and Engineering Statistics website can assist in this goal (18). To read more about teaching ideological awareness in biology classrooms, we recommend (17) and (16). While these activities have high potential to benefit students, instructors must be prepared to engage in potentially difficult discussions surrounding race, gender, tokenization, and representation. Problematically, previous research shows instructors infrequently notice racialized events in the classroom, in part due to color-evasive ideologies, which are pervasive in STEM culture (19). Color-evasive ideologies deny that inequalities relate to racism exist, and instead offer different explanations (20, 21). To address this and increase student comfort in discussing topics related to race, we recommend that instructors seek out resources to become more familiar with racial literacy topics (*e.g.,* 19). For example, critical scholarship and anti-racist research at the intersection of biology and education include (23–25).

SCIENTIFIC TEACHING THEMES

Active Learning

Several active learning strategies were used in this lesson (26). This activity brings authentic data into the classroom (Supporting File S1), guiding students through the scientific method. Students evaluate data, discuss literature, make claims based on quantitative evidence, and make observations and predictions. Previous research that tested the impact of students engaging in the practices of science in the classroom showed improvement in the ability to construct scientific explanations, and increased self-efficacy in data-related tasks and interest in STEM careers (27). At the end of the activity, students are asked to design their own experiments based on what they have learned. While students do not carry out those experiments, previous calls for change encourage student inquiry in lecture-based activities (28, 29). Most inquiry research in biology is based on modified laboratory courses, and have demonstrated promising results for students including enhanced sense of project ownership, greater identification as scientists, and graduation rates and completion in STEM (30, 31). Group activities are also strongly recommended for this lesson. As any scientific career requires the skills to collaborate, in-class group work offers students with the opportunity to improve communication and collaboration. Group work and cooperative learning is often assumed to include between two to six students (32), and has been shown to improve student performance (33, 34).

Assessment

Various forms of formative assessments are used to evaluate student comprehension of material. Instructors can either rely entirely on the worksheet provided with the lesson or turn some of the multiple choice questions into iClickers to quiz students (35, 36). The worksheet prompts several open-ended responses that instructors can ask students to turn in or they can engage in a peer review activity, where students swap worksheets and discuss each other's answers. Peer review and revision provide opportunities for students to correct their mistakes and consider new perspectives (37). Additionally, the experimental design assignment at the end of the activity can be used to evaluate the students' understanding of the scientific method, and the variables associated with experimental design.

Inclusive Teaching

Diversity, equity, and inclusion underpins the design and focus of this class lesson. Specifically, this lesson explores the representation of scientists in biology textbooks. Perceptions of who can do science are shaped by contextual cues, and previous work shows exposure to stereotypical representations of scientists are persistent in biology, and impact interest in science among women and students of color (38–41). This lesson promotes understanding of who has historically had access to biology (*i.e.,* white men) and has students reflect on what this communicates to aspiring biology students.

Beyond the content in the activity, plenty of inclusive teaching opportunities exist throughout the lesson. We recommend using 'many hands, many voices' to encourage students to participate and share ideas. In this strategy, an instructor waits for multiple hands to raise before starting to call on students. This extra wait time broadens participation as well as the range of ideas shared in the class (42). Students work in small groups for many of the activities, which allows students to rehearse their ideas and gain confidence, lowering the stakes of participating in class (43). For example, students draw predictive graphs on white boards with their groups and the instructor encourages groups to walk around and examine what others have drawn. Additionally, given the nature of this topic, we recommend instructors praise effort and improvement of student understanding. Biology students may have never encountered discussions that sit at the intersection of biology and society, or may not expect these discussions to occur in their biology course. Supporting student responses recognizes growth and encourages participation (44).

LESSON PLAN

Components of the Class

Introductory Lecture

This lecture sets the stage for the forthcoming activity and defines the scientific method (Table 1). First, the instructor describes the scientific method as a process of inquiry that includes making observations, asking questions, forming testable explanations (hypotheses), and making predictions (Supporting File S2). Then, scientists develop experiments to test the predictions, and analyze the results to form conclusions. In the presentation, the example focuses on the question of whether increasing pre-season football practices from 1 practice per day to 3 practices per day is associated with more winning, with students walking through each step of the scientific method as the example is presented. The lecture then cautions on the limitations of science and then contrasts the process of science to that of pseudoscience.

The lecture concludes with various types of scientific studies, defining descriptive studies, analytical studies, correlational studies, and experimental causation studies. The supporting PowerPoint file includes examples of these terms, but they are easily interchangeable with geographically local examples or with examples of science being conducted at the instructor's institution.

Student Handout

1. Wood *et al.*, 2020 Excerpt

Students read a short excerpt from the Wood *et al.* paper describing the important influence of curricular materials and role models in science (1) (Table 1). The purpose of this excerpt is to highlight the influence that curricular materials have on students, and the importance of seeing oneself in science through these materials (Supporting File S1).

2. Textbook Data Collection

Next, students are instructed to find 10 random photos of scientists in their biology textbook (Table 1). This is a good opportunity to ask students how to randomize the process of selecting scientists in a way that will not bias sampling. One suggestion might be to use a random number generator and insert the number of pages in the textbook, then move forward/backwards from that page until they encounter a scientist. Wood *et al.* (1) found there to be an average of 164 scientists per textbooks, so students will likely encounter one easily using this approach. If the class doesn't have a textbook, students can find the most recent edition of any introductory biology textbook at the library. As an online option, students can use the following open access text, available as a PDF at OpenStax. As a helpful tip, if students are using a web-based text, they can search for key term "Scientist" and scroll through search results to locate scientists. For each scientist, students fill in a table to report their name, perceived gender, race, age, other details on their visible appearance, and the activities in the photo (*e.g.,* looking through a microscope, standing and smiling) (Supporting File S1).

Note, in the Wood *et al*. paper, the researchers stressed the limitations of their work as it related to gender and race/ethnicity assignments of scientists. For binary gender, they identified scientists as either men or women based on the pronouns used in the textbooks to describe them. If gender could not be inferred from the textbook, the researchers used their Wikipedia profile information. However, doing this made several assumptions about the scientist that were in some cases impossible to verify, especially for historical scientists. One assumption was scientists were cisgender and identified with gender that aligns with their gender presentation. Defining gender expression and describing the limitations of the researchers' methods may be an important inclusive measure, particularly for students who identify with a gender that is marginalized. For more information about addressing sex and gender in the biology classroom we recommend (45). For race/ethnicity assignments, the researchers used the National Institutes of Health guidelines for defining racial categories in the context of the United States (46) as American Indian or Alaska Native, Asian, Black or African American, Hispanic or Latino, Native Hawaiian or Other Pacific Islander, or White. These are also limiting and imperfect, normally used for classification of federal data. The scientists used the term 'scientists of color' to describe all scientists who are not white, while acknowledging this does not recognize the variation within and among groups. Some individuals in this classification might not identify with the term or reject the term. Further, as the authors pointed out, they are established by an authority (rather than the individual), and do not recognize people who are mixed race. Importantly, they conclude with "binary gender and race are only two of many human social identities that have subpopulations which are marginalized and under-represented in STEM fields; while imperfect, our categories allow us to establish baselines of identity representation in the most commonly used biology textbooks in the US." As the students complete this task, we strongly recommend instructors communicate these limitations to the activity.

After completing the table, students should discuss what these photos imply about the types of people who do science with a partner or group. At the time of this article, our experience has consistently been that students find most scientists to be older, masculine, and white. The instructor can call on several students to participate.

3. Graphical Predictions

Students graph their predictions of scientists with different identities (perceived gender and race) as they change over the history of biological discoveries (Table 1). In Wood *et al.* (1), the 'history of biological discoveries' referred to the citations from the textbooks for which the scientist was mentioned. This is because scientists are mentioned in textbooks in conjunction with some groundbreaking work at the forefront of science. After students discuss their graphs with their group, instructors reveal the actual data of scientist representation over the history of biological discovery from the Wood *et al.* (1) data in the lecture presentation (Supporting File S2). Notably, while white women scientists have increased in representation over time, scientists of color are relatively underrepresented, though increasing in representation among more contemporary citations. Some groups were not represented at all. For example, researchers did not observe any examples of a Black woman scientists across the textbooks. This activity asks students to make many predictions (eight), and if the instructor is worried about time, they could modify this part of the activity to reduce the number of predictions.

4. Reflection

Students reflect on the publication, the activity, and the extent to which the data they collected align with the Wood *et al.* (1) study (Table 1). The last question asks how these results might impact student perceptions of who can be a scientist. Instructors might encourage students to discuss their responses with a partner and share with the class. In the lecture presentation (Supporting File S2), the instructor presents and interprets one more graph from Wood *et al.* (1) which shows the amount of time it would take, assuming current rates of change, for textbook representations to reflect the proportion of individuals with different identities (*e.g.,* Asian, or Black/African American) in the biology student population and the U.S. population. For example, assuming current rates of change, if textbook citations from Black/African American scientists continue at the same rate, it will take over 1000 years to reflect the general population in the United States (14%), and nearly 500 years to reflect the biology student population (7.7%). Among Hispanic/Latine scientists highlighted in textbooks, the researchers projected it will take 45 years until they reflect the general population in the United States and 30 years until they reflect the biology student population. This part of the discussion is particularly important to illustrate the dramatic extent that barriers have held back individuals on the basis of their race, gender, or other factors. In our experience as authors of the featured activity (1), we have found that some individuals interpret these stark findings with a shrug, communicating a dangerous message that there is just something inherently different about white men that justify their disproportionate inclusion in science textbooks. Even among researchers advocating for justice and inclusion in STEM, there are still debates about the nature and magnitude of problems posed by the lack of representation in STEM and the best ways to deal with them. Previous work suggests instructors worry that the students who hold the strongest biases will be the most vocal (47), but this is far from our experience, even in the relatively conservative southeastern United States where we have implemented this module. Even so, we recommend instructors are intentional in how they discuss the research, ask questions, respond to students, and are prepared for challenging discussions. We have found that reflections at the end of the activity give students the time and space to consider the implications of this work and the activity.

The instructor may ask (i) "why does this matter? And what are the implications for students in biology, our society, and science?" Here students consider the societal implications of these results. In our previous experience teaching this module, students ponder impacts of a monolithic group of scientists on the most pressing scientific and societal issues. Such a group may prioritize and fund projects that do not reflect the needs of the broader population it serves. In contrast, a group composed of many backgrounds bring different perspectives that are less likely to bias outcomes or misinterpret results. (ii) "What new questions arise from the activity?" This question models the scientific method because often results inspire new investigations and questions to explore. From our previous experience teaching this module, students have asked far-ranging questions that were inspired by the activity, such as how these results would compare to other STEM textbooks (*e.g.,* physics or chemistry), how each scientist is described (*e.g.,* how much text is used to describe different groups), the visual depictions of scientists in textbooks, and whether any text that humanizes the scientists are included in the descriptions of scientists. (iii) "What do you think needs to change in the sciences to encourage more diverse representation?" Here students think about what actions they can take to promote meaningful change. From our previous experience teaching this module, this question has resulted in the most varied responses. Students generally start by advocating for increased representation of scientists in textbooks, but also call for more equity, diversity, and inclusion across higher education. For some students, this may be the first time they have thought about this question, and others may have targeted and specific ideas that would reduce systemic barriers and encourage more diverse representation (Supporting File S2).

In the process of the larger group discussion, instructors may wonder how to have a respectful conversation among students who enter the classroom holding varying opinions and ideologies. Griswold and Chowning (48) considered several strategies to scaffold student understanding and discussions of ethical issues in the context of socioscientific classroom activities, while supporting students' abilities to arrive at evidence-based decisions about those activities. We encourage instructors to read this work for ideas on how to promote safe and structured opportunities for students to discuss potentially sensitive topics. For example, they recommend providing using the principles-based ethical framework developed by Beauchamp and Childress (49) prior to launching into discussion. This follows the three following tenets in which students should: (i) respect the inherent worth and dignity for each individual and acknowledge each person's right to make their own choices and opinions; (ii) prioritize maximizing benefits and minimizing harms; (iii) center justice, which considers how to treat people fairly and equitably. Using intentional strategies such as these can provide an effective way for students to structure their thoughts and justify their positions.

<u>5. Designing an Experiment</u>

Students design an experiment to test if textbook representation varies by the age of the scientist (Table 1). While we use scientist age as the example, this exercise can be accomplished with any identity in science. Students are encouraged to use writing, drawings, and graphs to demonstrate the experimental design. Students discuss the experiments with their group and the instructor encourages students to share with the class (Supporting File S1).

<u>6. Assessment</u>

The assessment can be completed at the end of class or as a post-course assignment. Six short answer or multiple-choice questions assess student knowledge of the scientific method, and resemble what students might encounter on a summative assessment.

1. List the steps of the scientific method in order.
2. A hypothesis must be all of the following except:
   a. Testable
   b. Proven
   c. Refutable
   d. Precise
3. Which of the following should be considered when determining scientific validity?
   a. Scientific Literacy
   b. Biases
   c. Means of sharing information
   d. All of the above
4. What type of study is the Wood *et al.* paper?
   a. Descriptive
   b. Analytical
   c. Correlational
   d. Experimental
5. According to the limitations of science, this study alone tells us whether our current practices are morally right or wrong.
   a. True
   b. False
6. If representation in biology and textbook representation are correlated, you can assume one variable leads to another (causation).
   a. True
   b. False

TEACHING DISCUSSION

The impact of this lesson was reported by the authors in previous research (17, 50). In (17), we implemented a curriculum consisting of this activity ("Representation in STEM") and two other modules that were meant to promote ideological awareness among students. Ideological awareness is "an understanding of biases, stereotypes, and assumptions that shape contemporary and historical science" (16). We found that the students who engaged with the curriculum reported a preference for these materials over those in a traditional biology curriculum, and that persons excluded because of their ethnicity and race (PEERs) reported greater approval than non-PEERs. Other research implemented a similar semester-long ideological awareness curriculum and students created concept maps for their final exam, which were coded for 'society' and 'biology' content (50). We compared the concept maps to another section who completed the same assignment after a semester with traditional biology content. In both sections, the concept map was worth 20% of students' final exam. Concept maps consist of nodes and links between the nodes representing relationships between concepts. Students in the ideologically aware section (which included the "Representation in STEM" module) included more societal content in their concept maps than the students in the traditional section. There were no differences in the amount of biology content across the two sections. In the ideologically aware section, 13% of concept maps mentioned representation in STEM specifically, along with many other societal nodes that aligned with the ideological awareness curriculum. Interestingly, in the traditional section, 15% of students mentioned "representation in STEM," even though this was not covered in class (50). This shows how this topic is of interest to students, even if they are not exposed to it in their curriculum.

Across these studies, the materials were delivered in a similar way to nonmajors students taking Introductory Biology during different semesters at the same public university in the southeast region of the United States. The Introductory Biology course was a three-credit class that includes two 75-minute class sessions each week. Because the materials required for this lesson can be shared electronically—consisting of a PowerPoint lecture, a worksheet, a PDF publication, and an e-textbook—this lesson is suitable for either online or in-person teaching formats. Additionally, the modular nature of the lesson lends itself well to shorter or longer classes, and certain elements can be completed as homework or in subsequent class periods.

Teaching ideologically aware topics such as representation in STEM is important for both nonmajors and biology majors populations. Previous reports suggest desired outcomes resulting from nonmajors participation in science are developed scientific literacy skills, or the ability to make sense of science that is relevant to their daily lives (51, 52). Considering the scientific method as it applies to societally relevant problems will assist in this goal. For biology majors, lower-level biology courses may one of few opportunities for students to discuss the prevalence of biases, stereotypes, and assumptions that shape the demographic landscape of scientists and science.

SUPPORTING MATERIALS

- S1. Representation in Science – Student handout
- S2. Representation in Science – Introduction slides

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Table 1. Lesson timeline. The lesson includes one 75-minute class period and one post-assignment.

Activity	Description	Estimated Time	Notes
Lecture			
Introductory lecture	The instructor describes the scientific method, its limitations, and defines pseudoscience. Then, the instructor goes through various types of scientific studies.	20 minutes	The supporting PowerPoint file includes examples of these terms, but they are easily interchangeable with geographically local examples or with examples of science being conducted at the instructor's institution (Supporting File S2).
Student Handout			
Students independently read summary of Wood *et al.* (1)	Excerpt from the Wood *et al.* (1) paper describing the important influence of role models in science.	5 minutes	Wood S, Henning JA, Chen L, McKibben T, Smith ML, Weber M, Zemenick A, Ballen CJ. 2020. A scientist like me: Demographic analysis of biology textbooks reveals both progress and long-term lags. Proc R Soc B 287:20200877. doi:10.1098/rspb.2020.0877. Supporting File S1.
Textbook data collection	Students find 10 random photos of scientists in their biology textbook and fill in their name, perceived gender, race, age, and any other relevant details regarding their visible appearance and the activities in the photo.	15 minutes for photo search and 5 minutes for discussion. Total = 20 minutes	Students can work in pairs. If the class doesn't have a textbook, students can find the most recent edition of any introductory biology textbook at the library. Or, as an online option, students can use an open access text, available as a PDF at OpenStax. Supporting File S1.
Graphical predictions	Students graph their predictions of scientists with different identities as they change over the history of biological discoveries. Instructor follows this exercise with a reveal of authentic data from Wood *et al.* (1).	15 minutes	First, students predict the representation of men (solid line) and women (dashed line) in science textbooks over time. Then, students use colored pencils or labeled lines to predict the intersectional representation of different race/ethnicities and gender in science textbooks over time. Supporting File S1.
Reflection	Students reflect on the results from the Wood *et al.* (1) study and their own data.	10 minutes	Students reflect on the publication and the extent to which their data align with the Wood *et al.* (1) study. The last question asks how these results might impact student perceptions of who can be a scientist. Instructors might encourage students discuss their responses with a partner and share with the class. Supporting File S1.
Designing an experiment	Students design an experiment testing if textbooks representation varies by the age of scientist.	5–10 minutes	If the instructor is running out of time, this can also be assigned as homework. Note this exercise can be accomplished with any identity in science. Students can discuss these experiments with a partner/group and instructors can encourage students to share with the class. Supporting File S1.
Post-Activity Assignment			
Assessment	Six short answer or multiple-choice questions that may be similar to those students will encounter on a summative assessment.	10 minutes	Supporting File S1.

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