Development of a Framework for the Culture of Scientific Research

Jessica Dewey,[†‡*] Gillian Roehrig,[†] and Anita Schuchardt[‡]
[†]STEM Education Center, University of Minnesota, St. Paul, MN 55108; [‡]Department of Biology Teaching and Learning, University of Minnesota, Minneapolis, MN 55455

ABSTRACT
Scientific research has a culture that can be challenging to enter. Different aspects of this culture may act as barriers or entry points for different people. Recognition of these barriers and entry points requires identifying aspects of the culture of scientific research and synthesizing them into a single, descriptive framework. A systematic literature review encompassing a two-pronged search strategy, descriptive mapping of ideas, and consensus building, was performed to identify aspects of scientific research culture. This resulted in the Culture of Scientific Research (CSR) Framework, composed of 31 cultural aspects categorized as either Practices, Norms/Expectations, or Values/Beliefs. Additional evidence of validity was collected through a survey that asked biological researchers to indicate which aspects in the framework were relevant to their experiences of research. The majority of survey respondents (n = 161) perceived the 31 aspects in the CSR Framework as relevant to biological research. This framework provides a consistent structure for describing the experiences of people engaging with the culture of scientific research. The literature review included literature from multiple disciplines, so the CSR Framework should be broadly applicable. Future applications of the CSR Framework include identifying possible barriers and entry points experienced by groups currently underrepresented in scientific research.

INTRODUCTION
Scientific research has its own culture made up of distinct aspects that identify and distinguish the processes scientists use to produce scientific knowledge from other academic fields, such as history (Lunetta *et al.*, 2007; Taras *et al.*, 2009). Students often experience the scientific research culture for the first time as undergraduates when they participate in research experiences (Auchincloss *et al.*, 2014). In these research experiences, undergraduates act as legitimate peripheral participants, interacting with the culture of scientific research, engaging in the work scientists do to produce knowledge, and learning how to participate in the field of scientific research (Lave and Wenger, 1991; Aikenhead, 1996; Lunetta *et al.*, 2007; American Association for the Advancement of Science, 2011; Gardner *et al.*, 2015) This process of entering into the culture of scientific research is called "border crossing" (Aikenhead, 1996).

Border crossing is a very individual experience that can be easy or challenging for different students (Aikenhead, 1996). Examining students' experiences of border crossing by identifying specific cultural aspects that could support (i.e., entry point) or challenge (i.e., barrier) their border crossing may help improve the success of more students. However, a single framework that specifies the cultural aspects of scientific research has not yet been established. This work aims to extend prior work by establishing a framework for the culture of scientific research through a systematic literature review.

The Culture of Scientific Research Context
Research can be carried out in a variety of places, such as academic institutions or industry-based companies. This paper will focus on the research done at academic

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*Address correspondence to: Jessica Dewey (jldewey@syr.edu).

institutions, because this is the context where most undergraduate students are first exposed to and participate in research. Within academic institutions, multiple types of research can occur, such as historical research or mathematics research. While there may be overlap in how each type of research is carried out or how interdisciplinary questions are addressed across fields, each field of research is unique. This paper will focus specifically on the scientific research field, which is comprised of the work carried out by graduate students, postdocs, and faculty in the scientific disciplines to produce scientific knowledge (Lunetta *et al.*, 2007; Bergquist and Pawlak, 2008).

Scientific research at academic institutions has its own core culture that is composed of specific aspects that identify and distinguish this field from other fields (Taras *et al.*, 2009). However, there are also many layers of culture present in different contexts that can impact how the core culture of academic scientific research looks and functions. Mainstream culture outside an institution, the overarching climate of different institutions, departmental cultures, the individual cultures of the members of an institution, and the microcultures created in research labs can all impact the culture of scientific research in different contexts (Thoman *et al.*, 2017; Reinholz *et al.*, 2019). The focus for this paper will be on the cultural aspects related to how scientific research is performed at academic institutions within the larger influences of institutional contexts and mainstream cultures. These aspects are distinct from common professional behaviors in science. For example, how scientists in different disciplines dress and socialize at conferences would be professional behaviors that are outside the scope of the academic scientific research culture context.

These core cultural aspects of scientific research are reflective of the dominant class in science (Carlone and Johnson, 2012). This dominant class has been represented, both historically and still today, by white, male, Western worldviews (Aikenhead, 1996; Seymour and Hewitt, 1997; Carlone and Johnson, 2007). Previous work has shown that the influences of white, male, Western worldviews in science can impact people's experiences of the culture of scientific research (Clancy *et al.*, 2014; Dutt, 2020; Barnes *et al.*, 2021). To understand the (white, male, Western) culture of scientific research, it is important to identify these core cultural aspects and use them to establish a framework. By establishing this framework, we are not advocating for the persistence of this culture. Instead, the framework can serve as a tool for future work that enables systematic examination of experiences of border crossing into this often exclusionary culture by different groups of students. This work will help lead to changes to the culture of scientific research to make it more inclusionary.

Theoretical Framework

Border crossing is the process of moving between the cultures of different worlds (Aikenhead, 1996). Students are asked to constantly border cross between disciplines in school, and students tend to have the most difficulty border crossing into the discipline of science (Aikenhead, 1996). This is true in higher education as well, where students are asked to learn about the field of scientific research by participating in research experiences in addition to learning about science content during lecture. One way for students to learn how to border cross into scientific research more successfully is through legitimate peripheral participation (Lave and Wenger, 1991). Legitimate peripheral participation was developed from research on apprenticeship in fields such as midwifery and tailoring and involves a newcomer to the field (a novice) learning to join a new field through mentorship by experts in that field (Lave and Wenger, 1991). The novice first starts on the periphery of this field, working directly with experts (mentors) in a community of practice to learn more about the field and how it works. The novice generally starts by observing the experts, but over time begins to participate in the legitimate practices of that field, eventually becoming part of the field's community of practice (Lave and Wenger, 1991).

Legitimate peripheral participation also occurs in the context of scientific research. Undergraduate students learn about scientific research by engaging with experts in the field and interacting with the culture of scientific research (Lave and Wenger, 1991; Thiry and Laursen, 2011; Auchincloss *et al.*, 2014). During these research experiences, undergraduate students work with experts who act as mentors (e.g., graduate students, postdoctoral research associates, or principal investigators) to learn how to perform various scientific practices, as well as how to think, act, and talk like the scientists around them in the lab (sometimes referred to as cultural capital; Thompson *et al.*, 2016), and how to define themselves as members in the field of scientific research (Lave and Wenger, 1991; Thiry and Laursen, 2011).

Students' experiences within these laboratory environments can impact their persistence in science (Cooper *et al.*, 2019; Limeri *et al.*, 2019), highlighting the importance of studying students' experiences of participating in scientific research. Working with mentors and legitimately participating in scientific research allows students to interact with the different aspects that make up the culture of the scientific research field. Researchers have previously examined the impact of the mentoring relationship on students' persistence in science (Aikens *et al.*, 2016, 2017). However, the interactions with the cultural aspects of scientific research can also impact students' border crossing experiences. Therefore, understanding how undergraduate students experience the culture of scientific research can inform our understanding of border crossing in this context and help to identify ways to make this border crossing successful for more students. While some previous work has investigated undergraduate students' experiences of the culture of scientific research, that work did not use a consistent definition of culture or single framework for the culture of scientific research, making it difficult to compare across these studies (e.g., Carlone and Johnson, 2007; Hurtado *et al.*, 2009).

The Need for a Framework

Aikenhead (1996) argues that one way to help students border cross more effectively is by designing interventions that specifically address borders students may face. Before these interventions can be designed, however, potential borders need to be identified. Generally, work in this area has investigated how student characteristics (such as gender, race/ethnicity, and other identities) can impact students' border-crossing experiences (e.g., Barton *et al.* 2008; Taconis and Kessels 2009). Other work has focused on how language or characteristics of a student's home life may impact border crossing (Costa, 1995; Moore, 2007). These perspectives imply that the diversity of students' individual and environmental characteristics may impact students' success in science, placing the burden on the individual to fit the system. This review will instead focus on identifying specific aspects of a culture, in this case the culture of scientific research. These cultural aspects may serve as the borders students need to cross and could be either negative borders (i.e., barriers) or positive borders (i.e., entry points) that either help or hinder a student's success with border crossing.

Previous work in the K–12 context has produced descriptions of science with the goal of producing educational resources for K–12 science educators to teach students about science (e.g., Lederman *et al.*, 2002; National Research Council, 2012). However, most students do not interact with academic scientific research and learn what it means to do science and be a scientific researcher until the undergraduate level. There has been work at the undergraduate level exploring a variety of outcomes from participating in research experiences both during direct mentorship and in laboratory courses (e.g., Science Identity Scale: Estrada *et al.*, 2011; Survey of Undergraduate Research Experiences and Classroom Undergraduate Research Experience Survey: Lopatto, 2004, 2009; the Laboratory Observation Protocol for Undergraduate STEM: Velasco *et al.*, 2016). However, none of these studies and their associated tools specifically focus on the culture of scientific research or student border crossing.

There has also been work done in history, philosophy, and sociology of science that describes portions of the culture of scientific research. These studies are often ethnographic in nature and aim to describe science from an outsider's perspective (e.g., Latour and Woolgar, 1979; Hacking, 1992; Resnik, 2007). However, there has been no synthesis of these ideas into a single, coherent framework. Such a framework is necessary to examine the experiences of undergraduate students as they encounter the culture of academic scientific research, because it would allow for more specific identification of cultural barriers and entry points that students may experience in different research settings. Having a framework that allows for the identification of cultural aspects that act as barriers and entry points to students will aid future studies of undergraduate student border crossing into scientific research. Understanding students' experiences of border crossing is important, because if students have difficulty border crossing into science, they likely will not pursue the science field later in life (Barton *et al.*, 2008).

The purpose of the current work is twofold: 1) to conduct a systematic literature review and synthesize the literature into a single framework describing the culture of scientific research as it is practiced by scientific researchers in academic institutions across science disciplines; and 2) to conduct an initial validity check by using a survey approach to empirically test the relevance of the framework to researchers in one discipline, biology. This paper is organized into two main parts. First, the systematic literature review will be described, and the resulting framework will be presented and discussed. Second, additional evidence based on the survey of the validity of the framework for biological research will be described.

Method for Developing a Framework

A systematic review of the literature was conducted to identify the cultural aspects of scientific research and synthesize them into a framework (Gough, 2007). Rather than reviewing the literature broadly to establish the state of a field, a systematic literature review uses a set of formal processes (e.g., defining a search strategy, defining inclusion and exclusion criteria, literature screening) to collect evidence in a clear, systematic way and can be used to develop new theory (Fink, 2005; Gough, 2007; Xiao and Watson, 2019). These reviews are conducted using established procedures and can cover a wide breadth of literature, resulting in useful and generalizable products (Gough, 2004; Wohlin *et al.*, 2012). First, inclusion criteria and the search strategy are defined. Then, an initial set of studies is identified through keyword searches, screened against the inclusion criteria, and used to identify more relevant literature through snowballing (Wohlin, 2014). The data gathered from systematic literature reviews can be synthesized into frameworks that expand on the state of knowledge in the field and can be used to guide future research (e.g., van Aalderen-Smeets *et al.*, 2012; Kalelioglu *et al.*, 2016; Zhao and Schuchardt, 2021). For this review, information related to the cultural aspects of scientific research has been extracted and synthesized from the final set of studies included in the review.

A systematic literature review was chosen as the method to develop this framework as opposed to interviews with practicing scientific researchers for multiple reasons. First, previous work that involved interviews with scientists has shown that scientists do not necessarily have fully informed or consistent views of the nature of science (Schwartz and Lederman, 2008; Bayir *et al.*, 2014). Second, literature suggests that "insiders" in a culture have a difficult time articulating the aspects of their culture without reflection and discussion with "outsiders" (Akkerman and Bakker, 2011). These findings suggest that collecting data by interviewing scientists who may not have thought about science or their scientific work in a philosophical way may result in an incomplete or inaccurate framework describing the culture of scientific research. Therefore, to collect data regarding the culture of scientific research in a way that represents a wide breadth of literature and perspectives, a systematic review of the literature was conducted.

The framework resulting from this systematic literature review is generated from and synthesizes previous work in this area, providing one line of evidence of the validity of the ideas in the framework. Additional evidence of validity was also collected to confirm that the ideas included in the framework align with current biological researchers' views of their discipline. The breadth of literature and range of perspectives used to establish this framework should result in a generalizable product, although rigorous testing of generalizability will require multiple future studies.

Defining Culture for the Purpose of the Systematic Literature Review

A single definition of culture was needed to guide the systematic literature review. Culture is a very broad topic and has been defined in many different ways in different fields (e.g., Malinowski, 1960; Banks, 1974; Shein, 2004). In general, the definitions overlap in that they treat culture as complex, multilevel, and shared within a group (Taras *et al.*, 2009). However, the wide range of ways in which culture has been defined across fields has resulted in the lack of a single, broadly used definition for culture (Taras *et al.*, 2009).

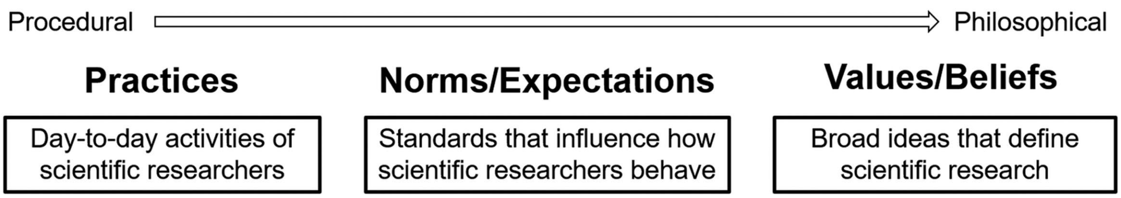

FIGURE 1. Defining the culture of scientific research.

To be useful for guiding the literature review, the definition of culture needed to include a small number of broad categories that encompassed ideas represented across multiple definitions. Additionally, given that the framework established through this literature review will be applied in the context of education, the definition of culture guiding this review should be consistent with previous educational work. Thus, this review uses the definition of Phelan *et al.* (1991), who define culture as the values, beliefs, norms, expectations, and actions of a group (descriptions in Figure 1). This definition is from the education field, has been used in multiple studies on border crossing (e.g., Aikenhead 1996; Costa 1995; Aikenhead and Jegede 1999), and presents a small number of broad categories within which different aspects of culture can be identified and grouped.

Phelan *et al.* (1991) consistently refer to "values and beliefs" as one idea, with examples such as family cohesiveness, academic achievement, and emotional openness. Given this paired use of values and beliefs, these two terms are combined into a single culture category for this review: Values/Beliefs. The Values/Beliefs category represents the broad ideas that are held in esteem by a group and used to define the group. Additionally, Phelan *et al.* (1991) use similar examples to describe both norms and expectations. Some examples of norms included studying for exams and helping others, while examples of expectations include graduating from high school and being available to give advice (Phelan *et al.*, 1991). Given the similar use of norms and expectations, these terms are also combined into a single category: Norms/Expectations. The Norms/Expectations category represents the standards that influence how a group and its members think and behave. Finally, because the "actions" of scientific research are more often referred to as practices, the third category of culture for this review is Practices, representing the day-to-day activities or actions of a group (Phelan *et al.*, 1991).

The three categories (Practices, Norms/Expectations, Values/Beliefs) that are used as a guide for defining culture in this review are highly related to one another and range from procedural views of a community (Practices) to more philosophical perspectives of a community (Values/Beliefs; Figure 1). Norms/Expectations can influence both Practices and Values/Beliefs, and in theory reciprocal relationships also exist (Frese, 2015). However, these categories still have explicit definitions and have been studied separately by both ethnographers and educational researchers (e.g., Mulkay, 1976; Pickering, 1992; Erduran and Dagher, 2014a).

METHODS FOR THE SYSTEMATIC LITERATURE REVIEW

This review used a two-pronged search strategy to identify relevant literature. First, a broad search of the literature related to the "culture of science" was performed to identify ethnographic-style studies of scientists working in their labs. These ethnographic studies provide rich descriptions of how scientific research is done, allowing many important aspects of the culture of scientific research to be identified. However, these ethnographic studies are often very context specific and may focus on small portions of the research process (e.g., writing a paper). Therefore, to supplement this literature search, a second, more guided search of the literature was performed for the three categories of culture being used for this review: Practices, Norms/Expectations, and Values/Beliefs. This search strategy was used to identify additional publications in which the authors explicitly identified cultural aspects within the three categories of scientific research. The studies identified through the category-specific search did not have to be ethnographic, rather they simply needed to identify aspects within the culture categories in some way. The objective of this two-pronged approach was to identify a wide body of literature from which cultural aspects of scientific research could be collected, reducing the chance of missing important cultural aspects of scientific research.

Selection Criteria, Search Strategy, and Screening

The databases of Google Scholar and ERIC were searched to find peer-reviewed publications in English, including both books and journal articles, from the mid-1970s to today. This starting time period was chosen because that is when researchers in the field of sociology of science began to use ethnographic methods that provided both insider and outsider views of how science functions (Collins, 1983; Knorr-Cetina, 1991). By studying science through both observation and participation in scientific practices, the sociology of science researchers could describe science in much greater detail (Knorr-Cetina, 1991). The time period of the mid-1970s to today spans major advancements in the field of science itself (e.g., the development of computers and the Internet); therefore, if there are any changes to the overall culture of scientific research as a result of these advancements, they should be reflected in the literature.

Broad Culture of Science Literature

Publication titles were searched for the terms: '"culture of science" -education', "ethnographic AND science," and "ethnography of science." These search terms were chosen because they are vague and would ideally result in a large pool of literature describing the culture of science. Searches using these terms resulted in the initial identification of 707 sources. Visual scanning of the titles was first performed to ensure that the publications were in the correct context and relevant to this literature review (i.e., scientific research happening in academic institutions). For example, the search done using the phrase "culture of science" -education resulted in an article entitled "Thinking of the Campus Culture of Science and

TABLE 1. Methods used to identify studies to be included in the literature review

Search strategy	Records identified and screened	Records included based on title/abstract	Records identified through snowballing	Full-text articles assessed	Studies included in review
Broad literature	707	15	30	45	28
Practices	194	16	20	36	15
Norms/Expectations	60	12	15	27	16
Values/Beliefs	94	12	12	24	19

Engineering Universities." While this article was situated within academic institutions and the science discipline, its focus was on campus culture instead of the culture of doing research. Publications like this that were situated in incorrect contexts (i.e., fell outside the defined boundaries of this work) were excluded from this review. Additionally, visual scanning of the titles and abstracts was used to identify publications that were ethnographic in nature. This visual scanning identified an initial pool of 15 relevant publications that focused on describing how scientific research is done in academic institutions. A snowball approach was then used to find additional publications that either referenced the initial set of identified publications or were referenced by the identified studies (Wohlin, 2014). These publications were then read in their entirety and either included or excluded based on their contents. Table 1 provides a summary of the number of publications identified and retained at each step of this process.

Culture Category-Specific Literature

The same databases were searched within the same time period for the literature search based on the three culture categories. Specific search phrases were used for each of the categories of culture to identify initial sets of literature. The phrases "practices of scientific research" and "practices of science" -education were used to search the literature databases for articles related to the Practices category. The phrases "norms of scientific research" and "norms of science" -education were used to search the literature databases for articles about the norms and expectations of scientific research. Additional searches were performed using the term "expectations" in place of "norms" and did not result in additional relevant literature for this category. The phrases "values of scientific research" and "values of science" -education were used as search terms for the Values/Beliefs category to identify articles about the values and beliefs of scientific research. Searches using the term "beliefs" in place of "values" did not result in additional relevant literature for this category. The phrases "scientific research" and "science" were both used when searching for literature, because the term "science" is often used in a way that encompasses both content and research. Using both terms reduced the potential of missing relevant work.

The results of the initial search for each culture category were screened first by title and abstract to check for relevance and correct context, as was done for the broad search strategy. The publications that passed this initial search were then read in their entirety. The snowball approach was also used in this search strategy to find additional publications that either referenced the initial set of identified publications or were referenced by the identified studies (Wohlin, 2014). Once publications had been identified, a full-text review was performed. To be included in the final review, the publications had to meet two criteria. First, the publications identified through this search strategy needed to explicitly identify specific cultural aspects of scientific research. For example, if a publication discussed the practices of science broadly without explicitly identifying any scientific research practices, this publication would be excluded. Second, the publications needed to either pull from literature on the history, sociology, and philosophy of science or be written in the context of the enactment of science (i.e., they needed to be relevant to academic scientific research). Articles applicable solely to the K–12 context were excluded. Table 1 provides a summary for each culture category of the number of publications identified and retained at each step of this process.

The two search strategies described identified 78 publications (24 books or book chapters, 54 articles) to be used in the final review. The snowball approach was only used on the initial set of articles identified through each search strategy for two reasons. First, publications began to be repeated in the first round of snowball searches. Second, many of the ideas discussed in the publications were being repeated, indicating a saturation of ideas.

Data Extraction and Synthesis

The final 78 publications included in this review were analyzed with the goal of identifying ideas that would represent cultural aspects of scientific research relevant to any of the three culture categories. Of the 78 publications, five were from the 1970s, 13 were from the 1980s, 16 were from the 1990s, 18 were from the 2000s, and 26 were from the 2010s to today. Additional descriptive information for all 78 publications is included in Supplemental Table S1. All 78 publications were descriptively mapped; the goal/purpose of each publication was summarized and all of the ideas that might represent cultural aspects of scientific research were listed in a table. Then, these ideas were coded as either Practices, Norms/Expectations, or Values/Beliefs based on the definitions of these categories. This coding was performed by the first author (J.D.), who is pursuing a doctoral degree in science education and participated in science research as an undergraduate, and independently by two colleagues who have both had experience with academic science research. One is a graduate student pursuing a doctoral degree in science education who also has a master's degree in botany, and the other is a postdoctoral researcher in science education who has a PhD in cellular, molecular, and developmental biology. The coding of the ideas was compared, and any disagreements on where ideas should be categorized were discussed until agreement was reached.

Once the ideas had been categorized as Practices, Norms/Expectations, or Values/Beliefs, they were grouped into themes within each category. Ideas had to be mentioned or discussed by at least four different publications (5% of all the publications included in the review) to be included as a separate theme. A cutoff was used to ensure that the themes being identified were broadly agreed upon in the literature and not idiosyncratic. These themes became the cultural aspects of scientific research. This thematic grouping was performed by the first author (J.D.) based on similarities and differences between the ideas, as well as the ways in which the ideas were discussed and described in the literature. For example, the practices of posing questions, developing hypotheses, and making predictions were all treated as initiating steps in the literature and were therefore grouped into a single theme. The first author (J.D.) then asked the last author (A.S.), an assistant professor in biology education research who has PhDs in human genetics/development and learning sciences, and the same two colleagues mentioned earlier to critically evaluate the groupings and highlight areas where they did not agree. Disagreements on the thematic groupings were discussed until agreement was reached. The results of this analysis led to the Culture of Scientific Research (CSR) Framework, which is described next.

THE CULTURE OF SCIENTIFIC RESEARCH (CSR) FRAMEWORK

This systematic literature review resulted in a framework comprised of 31 cultural aspects within the three broad categories of Practices, Norms/Expectations, and Values/Beliefs (Figure 2). These broad categories are described and discussed in the following sections, along with a few descriptions of individual aspects. Each aspect in the CSR Framework was mentioned by multiple publications, ranging from four to 47 sources. The descriptions do not discuss all of the aspects included in the CSR Framework and do not cite all of the sources on which they are based. Tables identifying the relevant citations for and descriptions of each cultural aspect are included in the Supplemental Material (Supplemental Tables S2–S4).

Practices

Practices are the day-to-day activities or actions of a group (Phelan *et al.*, 1991). Fifty-four of the 78 sources used in this review mentioned ideas that were categorized as practices. There was a great deal of agreement in the literature on the practices of scientific research across both the ethnographic descriptions of scientific research and the articles that more specifically identified lists of practices. From these 54 publications, 13 different Practices were identified (Figure 2; Supplemental Table S2). To highlight some of the finer distinctions between these Practices, we describe four of them in the following sections. Descriptions of the other Practices can be found in Supplemental Table S2.

Scientists Produce and Use Representations of Phenomena. An important practice that appeared in four sources that were mostly ethnographic was producing and using representations of phenomena when performing scientific research (Collins, 1983). Examples from the literature of these representations include graphs, images, and tables (Collins, 1983; Evagorou *et al.*, 2015). These representations, sometimes referred to as "models of" (Gouvea and Passmore, 2017), are meant to be descriptive of phenomena. One example would be a fluorescently labeled image showing the presence of antibodies because it is used to describe the location and existence of antibodies without explaining anything about the phenomenon. In this way, representations are distinct from models, which are discussed next.

Scientists Develop and Use Models. The literature also referenced the development and use of models as a potential practice of scientific research (Ibrahim *et al.*, 2017). In contrast to representations, which simply describe phenomena, models, or "models for," are meant to be explanatory (Gouvea and Passmore, 2017). An example of a model would be a schematic of the process for how antibodies are transported to their destinations, because it explains how a phenomenon occurs. According to the literature, models are not always part of an investigation. When they are developed and used during an investigation, these models can be both physical and mathematical (Hacking, 1992; Douglas, 2000; Nersessian, 2006) and include simulations (American Association for the Advancement of Science, 2011).

Scientists Analyze Data. A widely agreed upon practice in the literature was data analysis (15 sources; Djørup and Kappel, 2013; Evagorou *et al.*, 2015; Mann, 2018). Many of these publications described how scientists perform statistical analyses (Allchin, 1999; Erduran and Dagher, 2014b) and classify and categorize their data (Latour, 1999; Douglas, 2000). Some of these sources also discussed how scientists minimize uncertainty or error in their data during data analysis (Tuana, 2013).

Scientists Apply and Use Computational Approaches. The use of a variety of computational approaches was mentioned in the literature as a separate practice from data analysis (American Association for the Advancement of Science, 2011). Seven sources discussed how scientists may use quantitative approaches such as mathematical calculations (Miranda and Damico, 2013), and power analyses (Mann, 2018) that are not necessarily part of the data analysis that scientists perform during scientific research. Additionally, while data are often analyzed quantitatively in science, they can also be analyzed using qualitative approaches (Douglas, 2000). Therefore, the uses of computational approaches and data analysis are separated in the CSR Framework. Mathematical modeling may be considered one computational approach that scientists use during scientific research; however, given the importance of developing and using models as a separate practice in the literature and the fact that not every computational approach involves modeling (nor does every model involve a computational approach), mathematical modeling is also considered to be separate from the practice of using computational approaches in the CSR Framework.

Norms/Expectations

Norms/Expectations are the standards that influence how a group and its members think and behave (Phelan *et al.*, 1991). Seventy-six of the 78 sources used in this review mentioned ideas that were categorized as norms or expectations. In contrast to the Practices category, the aspects within this category were more commonly contested in the literature. One reason for this is that the word "norm" was defined in a variety of ways in the literature. For example, Stehr (1978) describes how norms can either be "ideological" or "enacted." Ideological norms are norms that are professed externally but may not

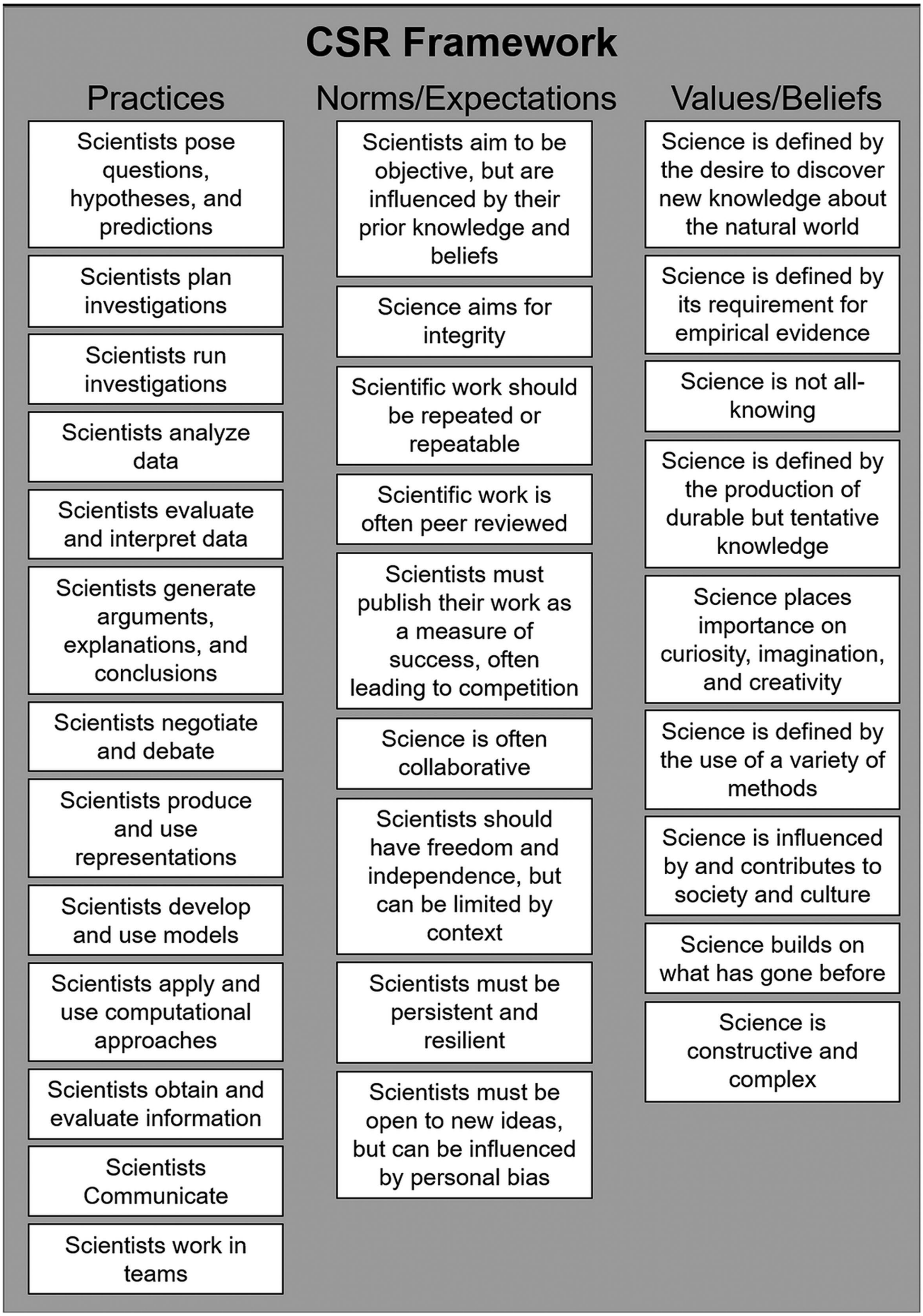

FIGURE 2. The CSR Framework.

actually be followed by scientists (i.e., what scientists want outsiders to think of them), while enacted norms are norms that actually regulate the behavior of scientists (Stehr, 1978). The various definitions of norms used in the literature has resulted in the identification of norms and expectations that are sometimes contradictory or differentially enacted, also referred to as counternorms. All of the norms/expectations identified in the literature were included in the CSR Framework even if they were contradictory. In total, nine Norms/Expectations were identified (Figure 2; descriptions in Supplemental Table S3). Four specific Norms/Expectations that encompass counternormative ideas are described in the following sections.

Scientists Aim to Be Objective but Are Influenced by Their Prior Knowledge and Beliefs. A commonly discussed (32 sources) and often contested expectation of science is that of objectivity. Many sources explained how science aims to produce new knowledge that is free from subjective bias (Artigas, 2008; Djørup and Kappel, 2013; Tuana, 2013; Elliot and Resnik, 2014). Examples of how objectivity can be achieved include the requirement for scientists to be emotionally neutral (Mitroff, 1974; Macfarlane and Cheng, 2008; Anderson *et al.*, 2010) and evaluate work only on its merit (Collins, 1982; Schmaus, 1983; Allchin, 1999; Kieff, 2000; Cao, 2014). However, while science aims to be objective, the literature recognizes that this is not always achieved. Seven sources discussed how work is sometimes evaluated on the reputation and past productivity or success of the scientist associated with the work (Mitroff, 1974; Mulkay, 1976; Yearley, 2004; Anderson *et al.*, 2010). Additionally, it was emphasized in the literature (23 sources) that scientific research is performed by humans, and therefore it is highly driven and impacted by people's values, opinions, beliefs, and attitudes (Mulkay and Gilbert, 1983; Elliot and Resnik, 2014). Rather than being value free (discussed in Carrier 2013), the literature posits that science is value laden, because it is performed by humans (Allchin, 1999). The acknowledgment that science is a human endeavor does not negate the expectation that science should strive to be objective. Rather, the impact that an individual scientist's background, beliefs, and so on have on the work should be recognized and reduced when possible (Carrier, 2013).

Scientists Must Publish Their Work as a Measure of Success, often Leading to Competition. Another expectation frequently detailed in the literature is that scientists will publish their work. Fourteen sources describe how a scientist's success is often measured through the number and quality of the scientist's publications (Knorr, 1977; Buxton, 2001; Cao, 2014). The literature also describes how this expectation to publish can lead to competition among scientists for things such as recognition, being the first to publish, author order and authorship, and publications in high impact-factor journals (Knorr, 1977; Knorr-Cetina, 1982; Anderson *et al.*, 2010).

Scientists Should Have Freedom and Independence but Can Be Limited by Context. A common expectation described in the literature (27 sources) is that scientific research should be characterized by individualism (Mulkay, 1976; Traweek, 1993; Anderson *et al.*, 2010) and independence (Kieff, 2000; Yearley, 2004) and that scientists should have the freedom to choose the projects on which they work (Anderson and Louis, 1994; Lacey, 1997; Resnik, 2007; Macfarlane and Cheng, 2008). However, there is recognition that researchers could be limited by their context. Some of the limitations that were mentioned in the literature included funding (Zenzen and Restivo, 1982; Fujimura, 1987; Koertge, 2005; Tuana, 2013), the research agenda of a lab (Nersessian, 2006), and the politics around funding and publications (Sandoval and Redman, 2015).

Scientists Must Be Open to New Ideas but Can Be Influenced by Personal Bias. Much of the literature (26 sources) describes how unexpected results are common in science and can result in discovery (Lynch, 1982; Gooding, 1992; Dunbar, 1995). Therefore, scientists are expected to be open-minded and consider all new evidence even if it conflicts with their own views or work (Stehr, 1978; Smokler, 1983; Allchin, 1999; Zeigler, 2009; Djørup and Kappel, 2013; Irzik and Nola, 2014). However, five sources also discussed the counternorm that sometimes scientists tend to believe strongly in their own work at the cost of being open-minded (Mitroff, 1974; Mulkay, 1976; Anderson *et al.*, 2010).

Values/Beliefs

Values/Beliefs are the broad ideas that are held in esteem by a group and used to define the group (Phelan *et al.*, 1991). Fifty-one of the 78 sources used for this review mentioned ideas that were categorized as values and beliefs (i.e., defining characteristics), and there was generally agreement on the characteristics that defined scientific research as a field. In total, nine Values/Beliefs were identified (Figure 2; descriptions in Supplemental Table S4). The three Values/Beliefs that were discussed most frequently in the literature are described in the following sections.

Science Is Defined by a Desire to Discover New Knowledge about the Natural World. The most commonly described defining characteristic of scientific research that came up in 32 publications is that the objective of science is to investigate unanswered questions to learn the truth about the natural world (Artigas, 2008; Rosenberg, 2008; Ayar and Yalvac, 2010; Cao, 2014). Additionally, the literature outlines how scientists are driven by a desire for knowledge and discovery (Stehr, 1978; Kalleberg, 2007; Anderson *et al.*, 2010; Heinrich, 2020).

Science Is Influenced by and Contributes to Society and Culture. One of the most common defining characteristics of science is that it does not function in a vacuum (Schmaus, 1983). Rather, 23 publications agree that science is impacted by historical, cultural, and social milieus (Tweney, 2004; Erduran and Dagher, 2014b). Additionally, it is commonly accepted in this literature that science impacts and contributes to the societies and cultures in which it is situated, of which there are many (McComas and Olson, 2002; Djørup and Kappel, 2013).

Science Is Defined by the Production of Durable but Tentative Knowledge. It is recognized in the literature (11 sources) that scientific research produces knowledge that is stable and reliable (McComas and Olson, 2002; Resnik, 2007). However, it was also commonly noted that scientific knowledge is dynamic and can change, both gradually and through revolutions, as scientific practices and theories progress over time (McComas and Olson, 2002; Sandoval and Redman, 2015). These two ideas are commonly discussed together in the literature and were therefore grouped in the CSR Framework, because it is important to recognize that scientific knowledge is reliable but not static.

Relationship to Previous Work

Previous work in the K–12 space has produced the *Framework for K–12 Science Education* to guide the teaching of K–12 science to improve students' scientific literacy. It identifies eight practices of science that K–12 students should engage with in their science classes (National Research Council, 2012). All eight of these practices are contained in the CSR Framework. However, the CSR Framework identifies cultural aspects of scientific research that one would need to know and understand to participate as a researcher in a scientific field (as opposed to being a general guide for educating K–12 students about what scientists do). Therefore, some of these practices have been unpacked and separated. For example, the practice of "obtaining, evaluating, and communicating" in the *K–12 Framework* was separated into "obtaining and evaluating information" and "communication" in the CSR Framework. Similarly, the *K–12 Framework* practice of "planning and carrying out investigations" was split into "planning investigations" and "running investigations" in the CSR Framework. The delineation of the practices in the CSR Framework provides a richer, finer-grained description of the activities of scientific researchers. For instance, while K–12 students may not need to know the distinction between planning and running an investigation, these are two distinct and important practices that scientists use to successfully conduct scientific research. A person trying to border cross into the scientific research field may experience planning an investigation as a cultural entry point but experience running an investigation as a barrier. This fine-grained separation of cultural aspects related to practices within the CSR Framework allows for these differential experiences to be examined. Additionally, the CSR Framework includes some practices that are not found in the *K–12 Framework*, such as "teamwork" and "producing and using representations." These practices were referenced frequently in the literature as important to performing scientific research and were therefore included as part of the CSR Framework.

In the same way that science practices have been outlined for K–12 education, the nature of scientific knowledge (NOS) has also been defined. A consensus view of NOS has been developed that identifies seven ideas specifically related to the nature of scientific knowledge that K–12 students should know and understand (Lederman *et al.* 2002). These ideas were developed for teaching students about science and not necessarily for specifying the culture of scientific research. Therefore, there was a need to determine which of these ideas were prevalent in the literature related to the culture of scientific research and whether there were other important Norms/Expectations or Values/Beliefs of scientific research beyond the consensus view of NOS. Six of the ideas in the consensus view of NOS were among the 18 aspects included in the Norms/Expectations and Values/Beliefs categories of the CSR Framework. One NOS idea that was not included in the CSR Framework was the idea that theories and laws are related but distinct from each other (Lederman *et al.* 2002; McComas and Olson, 2002). This idea is more a statement of fact about the nature of scientific knowledge than a practice, a standard driving behavior (Norm/Expectation), or a defining characteristic of scientific research (Value/Belief). Therefore, it was not included in the final CSR Framework. While the CSR Framework includes some of the ideas from the consensus view of NOS, it includes aspects from other literature as well to produce a more comprehensive description of the culture of scientific research.

At the undergraduate level, the *Vision and Change in Undergraduate Biology Education* report outlines six core competencies that students need to develop to achieve biological literacy (American Association for the Advancement of Science, 2011). These competencies are skills that students should have when they complete their undergraduate experiences and are not necessarily specifying the culture of scientific research. Some of these core competencies overlap with aspects in all three categories of the CSR Framework. For example, "the ability to use quantitative reasoning" and "the ability to use modeling and simulation" are similar to Practices in the CSR Framework. Additionally, "the ability to understand the relationship between science and society" is similar to a Value/Belief in the CSR Framework. The core competencies in *Vision and Change* were recently used to develop the BioSkills Guide, a tool that articulates more specific program- and course-level outcomes for students (Clemmons *et al.*, 2020). There is significant overlap between the Practices in the CSR Framework and the course-level outcomes described in the BioSkills Guide. For example, the Information Literacy program-level learning outcome in the BioSkills Guide aligns with the Practice of "obtaining and evaluating information" in the CSR Framework. However, there are also differences in the way certain practices are separated and grouped and the scope of the two tools. For example, the BioSkills Guide includes the course-level outcome of Creating and Interpreting Informative Graphs and Other Data Visualizations in the program-level outcome of Quantitative & Computational Data Analysis under the core competency of Quantitative Reasoning. In contrast, the Practices of "producing and using representations," "data analysis," and "using computational approaches" are all separate in the CSR Framework based on how they were discussed in the literature. Additionally, the BioSkills Guide includes some outcomes, such as Metacognition, that relate to learning in general and would not be considered cultural aspects of scientific research.

The CSR Framework is not meant to be used for the same educational purposes as the *K–12 Framework*, the consensus view of NOS, the *Vision and Change* report, or the BioSkills Guide (Lederman *et al.*, 2002; American Association for the Advancement of Science, 2011; National Research Council, 2012; Clemmons *et al.*, 2020). Instead, the CSR Framework is meant to provide a detailed set of cultural aspects that can be used to describe people's diverse experiences of the academic scientific research culture. The fine-grained descriptions of the cultural aspects of scientific research included in the CSR Framework (located in the text and the Supplemental Material) provide the level of detail needed to support research that explores disciplinary differences and the barriers and entry points people experience when trying to border cross into this field.

The Interrelatedness of the CSR Framework Categories

While the 31 aspects in the CSR Framework have been defined individually and organized within a specific category (Practices, Norms/Expectations, or Values/Beliefs), it is important to recognize that they are highly interrelated and can impact one another (Frese, 2015). For example, the norm of collaboration in scientific research often leads to the practice of teamwork. In the CSR Framework "teamwork" is specific to the actions taken that allow scientists to work together, while "collaboration" is a broader expectation of the scientific community at large. Similarly, Norms/Expectations such as "integrity" and "peer review" allow the knowledge produced by scientific research to be durable (Value/Belief). The aspects are all separate and distinct, but they also impact one another and function together.

Ideas Excluded from the CSR Framework

The CSR Framework does not include every possible cultural aspect that could apply to scientific research. Multiple ideas came up a single time in this review, such as machismo (Restivo, 1994), abstractness (Hildebrand, 2007), balancing ability and work ethic (Buxton, 2001), and living and working in unfamiliar settings (Mody, 2015). While these individual ideas may be applicable in some contexts, they were not broadly discussed in the literature, and some of these ideas fell outside the bounds of the academic scientific research culture context defined for this paper. Given that the CSR Framework is intended to be generalizable to multiple contexts, the lack of a broad discussion of these ideas in the literature resulted in them being excluded. Additional research may reveal a broader applicability of some of these ideas, and the CSR Framework could be modified to include them.

Modifiability of the CSR Framework

The CSR Framework is not meant to be a static, singular portrayal of the culture of scientific research. Rather, the CSR Framework includes cultural aspects that were discussed multiple times in the literature within the larger influences of different institutional and societal contexts. In the same way that general patterns are used in qualitative research and averages are reported in quantitative research, a consensus set of aspects was chosen to describe what is happening most of the time in the field of scientific research. This means that some aspects included in the CSR Framework may be more or less salient in different contexts. Broader societal cultures, institutional culture, disciplinary culture, and the culture of different labs can all influence how the scientific research culture functions in different contexts. Having the CSR Framework as a guide will allow for the identification of aspects that are more or less salient in different contexts, and then the CSR Framework can be modified to be more relevant for these contexts. Aspects within the CSR Framework can be merged or removed or new aspects can be added based on their applicability to different contexts.

ADDITIONAL VALIDATION OF THE CSR FRAMEWORK WITH BIOLOGICAL RESEARCHERS

This paper extends prior work on the culture of scientific research by establishing a single framework synthesizing the cultural aspects of scientific research through a systematic literature review. The literature review provided content evidence for the validity of the CSR Framework. To provide additional evidence for the validity of the CSR Framework specifically in the discipline of biology, we used a survey to conduct an initial validity check to determine whether practicing biological researchers agree that the ideas included in the CSR Framework are relevant to their experiences of scientific research. This validation study was reviewed and determined to be exempt by the University of Minnesota Institutional Review Board (STUDY00003109).

Data Collection

Data were collected through a survey that asked biological researchers to determine whether the aspects in the CSR Framework were relevant to their experiences of biological research. The survey was developed on Qualtrics by the authors, piloted with five biology education colleagues, and edited based on their feedback. The survey started with background questions about the respondent's discipline, career stage, and amount of time spent engaged in the process of biological research. Then, a question was shown that asked respondents to choose whether each of the 31 aspects in the framework were relevant or not relevant to their experiences of engaging in the process of biological research. Only the names of the aspects, not the descriptions, were provided to respondents. Through an open-ended question, respondents were then given the opportunity to explain why they chose "not relevant" for any of the aspects. The goal of this part of the survey was to determine how well the aspects identified from the literature aligned with biological researchers' views of their discipline. An open-ended question that asked respondents to share whether there were any aspects missing from our list was included to identify potential avenues for future research regarding additional aspects that could be included in the framework. Finally, respondents were asked demographic questions regarding gender identity, race/ethnicity, and institution type. The survey questions are included in the Supplemental Material. The survey was distributed broadly through Listservs (e.g., ECOLOG, SABER), departmental emails, emails to colleges of biological sciences, and personal connections to reach as many biological researchers as possible. Additionally, an effort was made to recruit a diverse set of biological researchers by sending the survey to networks with specific demographics (e.g., the Re-Envisioning Culture Network, a group that strives to enhance the science, technology, engineering, and mathematics experiences and outcomes of Black undergraduate students in the biological sciences). In total, there were 161 complete responses, representing a range of disciplines, career stages, institution types, and identities (Table 2).

Data Analysis

The proportion of survey respondents who indicated that each aspect in the CSR Framework was relevant to their experiences of biological research was calculated. Responses were also analyzed by career stage, discipline, gender identity, race/ethnicity, and institution type. Respondents' open-ended responses to the question regarding ideas that were missing from the framework were reviewed to identify any novel ideas that could be investigated in the future.

RESULTS

The proportion of survey respondents who chose "relevant" for each of the 31 aspects in the CSR Framework ranged from 80% to 100%, with an average of 95% (Table 3). The Values/Beliefs category had an average relevance across aspects of 96%, followed by Norms/Expectations (95%) and Practices (94%). The aspect selected as relevant by the fewest number of respondents was the Practice of "negotiation and debate" (80%; Table 3). The aspect with the highest proportion relevant was the Practice of "evaluate and interpret data" (Table 3). There were not major differences in the proportion relevant across career stage,

TABLE 2. Demographics of survey participants ($n = 161$)

Demographic	Survey participants	Demographic	Survey participants	Demographic	Survey participants
Career stage		Gender identity		Institution type[b]	
Graduate student	51	Woman	101	R1	81
Postdoc	19	Man	48	R2/R3	34
Assistant professor	23	Nonbinary	4	PUI	16
Associate professor	20	Transgender	2	Master's	6
Professor	22	Genderfluid/nonconforming	2	MSI	2
Other	26	Not disclosed	4	Two or more	15
Discipline[a]		Race/ethnicity		Other	7
EEB	122	White	130		
MCDBG	58	Latinx	10		
Biochem	12	Asian	6		
PlantMicro	48	Black	1		
Comp	12	Multiracial/ethnic	7		
Neuro	7	Not disclosed	7		
Other	26				

[a]Survey respondents were given the option to choose multiple disciplines that applied to their biological research. To summarize these data, broad categories of disciplines were defined: EEB, ecology, evolution, and behavior; MCDBG, molecular, cellular, developmental biology, and genetics; Biochem, biochemistry; PlantMicro, plant and microbial biology; Comp, computational biology; Neuro, neuroscience. Respondents who chose multiple disciplines are represented multiple times in this table.
[b]PUI, primarily undergraduate institution; MSI, minority-serving institution.

discipline, gender identity, race/ethnicity, or institution type (data in Supplemental Tables S5–S9).

Responses to an open-ended question asking respondents to explain why they chose selected aspects as "not relevant" indicated that respondents mostly chose "not relevant" for aspects in the framework that were either not *always* relevant or not relevant *to everyone*. For example, one respondent said, "Some are more relevant to certain areas than others. On the molecular side, my own experiences do not always develop and use 'models,' since it's often impossible for most questions." Another respondent said, "Some of the statements I selected as not relevant merely meant they weren't as applicable to my experience even though I agree they are generally part of biological research." Additionally, respondents did not fully understand or agree with the words used in some of the aspect names, resulting in those aspects being identified as "not relevant." For example, one respondent commented that "I am also not sure that biological researchers negotiate much about research, though they certainly debate." A different respondent said, "I don't understand the question about 'representations.' What does that mean?" As a result, fewer proportions of respondents deemed these two Practices, "negotiation and debate" and "produce and use representations," as relevant (80% and 85% respectively).

Respondents were also given the option to list any additional aspects that they thought were relevant to their experiences that were not included in the survey. This question was included on the survey to identify potential avenues for future research regarding the culture of scientific research specifically in the discipline of biology. In total, 58 separate ideas were mentioned by respondents. Of the 58 ideas, 33 were already encompassed by the framework. For example, one respondent said, "I use both quantitative and qualitative methods as a biological researcher." This idea of using different types of methods

TABLE 3. Relevance of the CSR Framework to biological researchers ($n = 161$)

Practices	Proportion relevant	Norms/Expectations	Proportion relevant	Values/Beliefs	Proportion relevant
Evaluate and interpret data	100%	Peer review	99%	Builds on what has gone before	99%
Pose questions	99%	Open to new ideas	99%	Variety of methods	99%
Analyze data	99%	Integrity	98%	Discovery	98%
Obtain and evaluate info	99%	Collaborative	97%	Constructive and complex	98%
Communication	98%	Persistent and resilient	97%	Curiosity/imagination	97%
Plan investigations	98%	Repeat investigations	96%	Durable but subject to change	96%
Generate arguments, explanations, conclusions	97%	Objective	96%	Empirical evidence	94%
Teamwork	96%	Publish as measure of success	86%	Cannot answer all questions	92%
Develop and use models	94%	Freedom and independence	82%	Influenced by/contributes to society	90%
Run investigations	92%				
Computational approaches	89%				
Produce representations	85%				
Negotiate and debate	80%				

to complete investigations is included in the Value/Belief that "Scientific researcher is defined by the use of a variety of methods" (Figure 2). Additionally, there were multiple comments that mentioned securing and needing funding, applying for grants, and politics. These ideas are included in the description of the Norm/Expectation that "Scientific researchers should have freedom and independence" specifically as counternormative ideas that limit freedom and independence (Figure 2), lines 460–468.

The remaining 25 ideas mentioned by respondents represented novel ideas that either did not occur in the systematic literature review used to develop the CSR Framework or lacked the broad support needed to represent a cultural aspect. Most of these ideas were not mentioned by at least 5% of respondents (eight out of 161) which was the cutoff for inclusion used in the literature review. These included ideas such as teaching (mentioned by three respondents) and management of people, projects, and budgets (mentioned by one respondent). These ideas provide a starting point for future investigations into the culture of scientific research in the discipline of biology. Seven respondents mentioned ideas related to gender and age bias, the impact of individual lab cultures, and the broader cultures and creeds of biological researchers. These are important influences to consider for future research into people's unique experiences of the culture of scientific research, especially given that the aspects identified in the CSR Framework represent white, male Western worldviews.

One idea that was mentioned by eight respondents was mentorship. In the theory of legitimate peripheral participation that was used as the theoretical framework for this paper, mentorship is the mechanism by which newcomers are introduced to a culture (Lave and Wenger, 1991). Mentorship does represent an important expectation of scientific researchers and has been shown to be important for helping students integrate into and persist in science (Aikens *et al.*, 2016, 2017; Joshi *et al.*, 2019; Limeri *et al.*, 2019). However, although it is extremely important to the transmission of a culture (Lave and Wenger, 1991), mentorship is not one of the defining aspects of the culture of scientific research. Therefore, it was not added to the CSR Framework.

DISCUSSION

Academic scientific research has a culture composed of distinct aspects that help to identify and distinguish it from other fields (Lunetta *et al.*, 2007; Taras *et al.*, 2009). Students are asked to border cross into the culture of scientific research when they participate in research experiences as undergraduates (Aikenhead, 1996; American Association for the Advancement of Science, 2011). Certain cultural aspects may act as barriers or entry points to students' border crossing, potentially impacting whether students pursue a career in scientific research (Aikenhead, 1996). A framework describing the culture of scientific research is needed to investigate undergraduate students' experiences of border crossing into scientific research. This paper describes the development of the CSR Framework through a systematic literature review that aimed to identify core cultural aspects of scientific research performed within academic institutions. The CSR Framework is composed of 31 aspects categorized as Practices, Norms/Expectations, and Values/Beliefs, categories that come from previous cultural studies of education (Phelan *et al.*, 1991). As evidenced through the systematic literature review described in this paper, much work has been done to describe the culture of scientific research. However, the cultural aspects described in the literature had not yet been synthesized. The CSR Framework expands on this prior work by providing a single, coherent tool describing the culture of scientific research. This framework is not meant to be an assessment or a list of ideas that students are required to know. Rather, the purpose of the CSR Framework is to provide a detailed set of cultural aspects that can be used to describe diverse experiences of the culture of scientific research.

The CSR Framework Is a Useful Tool for Understanding the Culture of Scientific Research

Two lines of evidence support the validity of the ideas contained within the CSR Framework and their reflection of the experiences of one group of researchers, biologists. First, a systematic literature review was conducted using prescribed methods and a wide breadth of literature to establish the framework. Systematic literature reviews conducted in this way with a clear collection of evidence can be used to develop new theory (Fink, 2005; Gough, 2007; Xiao and Watson, 2019). Data collected through systematic literature reviews can be synthesized into frameworks that expand on the current knowledge of a field and can be used to guide future research (e.g., Aalderen-Smeets *et al.*, 2012; Kalelioglu *et al.*, 2016; Zhao and Schuchardt, 2021). All of the aspects in the CSR Framework are supported by four to 47 different publications. Additionally, by using the snowballing method to search for additional relevant literature after establishing an initial set of publications identified through keyword searches, saturation of both published literature as well as new ideas was reached during the literature review. In total, these points provide one piece of evidence for the validity of the ideas in the framework as represented in literature on the culture of scientific research.

Second, 80% or more of the biological researchers 'surveyed for this paper recognized all of the aspects in the CSR Framework as relevant to biological research. In general, when survey respondents chose "not relevant," their explanations indicated that the reason for this selection was because the aspect was perceived as only relevant to some groups or disciplines within biology or the aspect was not always relevant. Survey respondents were also asked to identify any ideas important to biological research that were not included in the names of aspects in the CSR Framework. Over half of the ideas mentioned were already encompassed in the framework. The results from the survey therefore provide evidence of the validity of the CSR Framework for one area of scientific research. These two lines of evidence support the use of the CSR Framework in exploring undergraduate students' experiences of the culture of scientific research in biology.

Generalizability of the CSR Framework

The CSR Framework was developed through a systematic literature review and synthesizes the cultural aspects of scientific research from a wide breadth of literature. Literature published' across time periods (1970s to today), in different locations, and across different science disciplines was used to develop the CSR Framework. Additionally, there were not major differences across the subdisciplines of biological research represented by the survey respondents with respect to the relevance of the aspects in the CSR Framework to biological research. These two points provide evidence that the CSR Framework has some amount of generalizability. However, data regarding the relevance of the CSR Framework to other disciplines in science have not been collected. These data should be collected in the future to determine the degree of generalizability of the CSR Framework.

FUTURE AVENUES FOR RESEARCH

Using the CSR Framework to Change Instruction or Mentorship

The 31 cultural aspects that make up the CSR Framework provide a high-resolution view of what it means to do science. In turn, the CSR framework will allow for characterization of students' diverse experiences of the culture of scientific research and a fine-grained identification of the cultural aspects that act as either barriers or entry points for different students. For example, an instructor teaching a lab course could now use the CSR Framework to examine how students are experiencing different cultural aspects of scientific research. By using questions that surface the cultural aspects that students found supportive or challenging, the instructor could identify which cultural aspects students experience as barriers or entry points and change the instruction to help reduce the barriers students experience. The instructor may find that planning an investigation is a cultural barrier for more students while running an investigation is more often experienced as a cultural entry point, allowing the instructor to focus on ways to make planning investigations less challenging for students.

Mentorship was a novel idea mentioned by eight survey respondents. This idea was not added to the CSR Framework, because mentorship is the mechanism used to introduce newcomers to a culture (Lave and Wenger, 1991) and is not a separate defining aspect of any one culture. However, the CSR Framework could provide a mechanism for extending prior research on mentorship (Aikens *et al.*, 2016, 2017; Joshi *et al.*, 2019; Limeri *et al.*, 2019). For example, investigation of the aspects that mentors emphasize or ignore when working with students and whether this emphasis changes based on students' identities could provide a fine-grained systematic examination of how mentors assist mentees with overcoming barriers and leveraging entry points. This work could lead to professional development for mentors that focuses on how best to assist their mentees to border cross into scientific research.

Understanding People's Experiences with the Culture of Scientific Research

The CSR Framework is a useful tool describing the culture of scientific research that now opens the door for many new avenues of research. Students' experiences and perceptions of the culture of scientific research can now be investigated during direct mentorship opportunities, traditional laboratory courses, and course-based undergraduate research experiences. Students' experiences can be compared across these contexts to determine which cultural aspects students are being exposed to during different research experiences. Students' experiences can also be compared across different identities to identify the cultural aspects that present barriers and entry points for underserved groups such as women, Black, and Latinx students. This is an especially important avenue of future research given that the aspects in the CSR Framework reflect the white, male, Western worldviews that represent the dominant class in science (Seymour and Hewitt, 1997; Carlone and Johnson, 2012). Additionally, this framework could be used to compare undergraduate students' experiences between disciplines, potentially revealing why some disciplines experience more disparity than others.

Comments from the survey respondents provide insight into other ways that the CSR Framework could be applied to investigate people's experiences of the culture of scientific research. There were some comments made by survey respondents about how an aspect was relevant to biological research, but not ideal. This occurred multiple times for the Norm/Expectation aspect that "scientific researchers publish their work as a measure of success, often leading to competition" as indicated by comments that mentioned that publication should not be the only measure of success. One respondent commented, "Publications play a role in measuring success and, yes, this can lead to competition in the field" but "helping young scientists learn to produce quality research is a measure of success for me." These types of comments highlight the importance of establishing this framework and studying people's experiences of the culture of scientific research. If measuring success through publications is viewed negatively by scientific researchers, it may eventually lead to them leaving the field. Additionally, if measuring success through publications represents a cultural barrier that newcomers to scientific research have a difficult time overcoming, it may impact who joins scientific research. Being able to explore people's experiences of cultural aspects of scientific research in this way through use of the CSR Framework will help to identify aspects that may need to be altered to make the culture of scientific research more inclusive.

The CSR Framework could also be used to investigate the intersection between the culture of scientific research and broader layers of culture and the potential impact on people's experiences of scientific research. Gender and age bias, harassment, and exclusion based on identity resulting from the white, male, Western worldviews that dominate scientific research could impact people's experiences and perceptions of the culture of scientific research (Clancy *et al.*, 2014; Cooper *et al.*, 2019; Dutt, 2020). Additionally, the microcultures of individual labs may have significant impacts on people's experiences of the culture of scientific research (Thoman *et al.*, 2017). With the CSR Framework established, these intersections can now be investigated. Future studies could also examine whether the proportion of different groups, such as women, in different disciplines correlates with a greater prevalence of particular aspects of the culture of scientific research. Finally, the CSR Framework could be used in conjunction with theory related to cultural capital to investigate how students' experiences and perceptions of the cultural aspects of scientific research may impact or relate to their cultural capital and ability to persist in science (Thompson and Jensen-Ryan, 2018; Cooper *et al.*, 2021).

LIMITATIONS OF THE CSR FRAMEWORK

The CSR Framework is being presented as an organizing tool to describe the culture of scientific research. It was developed based on a systematic literature review that included literature collected through two different search strategies and many different keyword searches. The goal of using two different search strategies was to collect cultural aspects from a wide body of literature, reducing the chance of missing important cultural aspects of scientific research. However, it is possible that some relevant literature was not included in this review, for example, literature that did not explicitly mention the word "culture." Future investigations could review literature that describes scientific research or the experiences of scientific researchers without referring to culture and compare it with work that explicitly references culture. Another limitation is that the CSR Framework is a general description covering multiple disciplines. Narrowing the literature review to specific fields of science could permit refinement of the CSR Framework for these fields.

The identities of the authors of the publications used in this systematic literature review may have influenced what was described in those publications. While this review included international literature that spanned a variety of contexts, the international literature often referenced Western ideas of scientific research. Therefore, the culture of scientific research in non-Western contexts may be underrepresented in this literature review. It will be important to examine whether the CSR Framework serves as a valid tool for describing scientific research culture in non-Western contexts. Finally, to identify themes that would become cultural aspects for the framework, a cutoff was used during the consensus-building stage of this review, whereby each theme had to be supported by at least four different publications (5% of the total). However, this cutoff could potentially bias the review against critical or nonnormative observations of the culture of scientific research.

IMPLICATIONS

This paper described a systematic literature review that resulted in a descriptive framework for understanding the culture of scientific research. Development of the CSR Framework allows for future explorations of experiences of the scientific research culture from people across disciplines of science, stages of advancement into the field of scientific research, and more. The establishment of the CSR Framework is a first step toward being able to identify cultural aspects that may act as barriers or entry points when students start to border cross into the culture of scientific research. The identification of these barriers and entry points can allow for the design of interventions that leverage entry points and reduce the barriers to participation in scientific research, leading to greater accessibility for all students, but especially students from underrepresented backgrounds.

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REFERENCES

Aikenhead, G. S. (1996). Science education: Border crossing into the subculture of science. *Studies in Science Education*, *27*(1), 1–52. https://doi.org/10.1080/03057269608560077

Aikenhead, G. S., & Jegede, O. J. (1999). Cross-cultural education: A cognitive explanation of a cultural phenomenon. *Journal of Research in Science Teaching*, *36*(3), 269–287.

Aikens, M. L., Robertson, M. M., Sadselia, S., Watkins, K., Evans, M., Runyon, C. R., … & Dolan, E. L. (2017). Race and gender differences in undergraduate research mentoring structures and research outcomes. *CBE—Life Sciences Education*, *16*(2), ar34. https://doi.org/10.1187/cbe.16-07-0211

Aikens, M. L., Sadselia, S., Watkins, K., Evans, M., Eby, L. T., & Dolan, E. L. (2016). A social capital perspective on the mentoring of undergraduate life science researchers: An empirical study of undergraduate–postgraduate–faculty triads. *CBE—Life Sciences Education*, *15*(2), ar16. https://doi.org/10.1187/cbe.15-10-0208

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of Educational Research*, *81*(2), 132–169. https://doi.org/10.3102/0034654311404435

Allchin, D. (1999). Values in science: An educational perspective. *Science & Education*, *8*(1), 1–12. https://doi.org/10.1023/A:1008600230536

American Association for the Advancement of Science. (2011). *Vision and change in undergraduate biology education*. Washington, DC.

Anderson, M. S., & Louis, K. S. (1994). The graduate student experience and subscription to the norms of science. *Research in Higher Education*, *35*(3), 273–299. https://doi.org/10.1007/BF02496825

Anderson, M. S., Ronning, E. A., DeVries, R., & Martinson, B. C. (2010). Extending the Mertonian norms: Scientists' subscription to norms of research. *Journal of Higher Education*, *81*(3), 366–393. https://doi.org/10.1353/jhe.0.0095

Artigas, M. (2008). Values in science. In Agazzi, E., & Minazzi, F. (Eds.), *Science and ethics: The axiological contexts of science* (pp. 115–124). Brussels, Germany: Peter Lang.

Auchincloss, L. C., Laursen, S. L., Branchaw, J. L., Eagan, K., Graham, M., Hanauer, D. I., …& Dolan, E. L. (2014). Assessment of course-based undergraduate research experiences: A meeting report. *CBE—Life Sciences Education*, *13*(1), 29–40. https://doi.org/10.1187/cbe.14-01-0004

Ayar, M. C., & Yalvac, B. (2010). A sociological standpoint to authentic scientific practices and its role in school science teaching, *Journal of Kirşehir Education Faculty*, *11*(4), 113–127.

Banks, J. A. (1974). Multicultural education: In search of definitions and goals. *This was a paper presented at the Association for Supervision and Curriculum Development's Institute on Cultural Pluralism in Chicago, 1974*.

Barnes, M. E., Maas, S. A., Roberts, J. A., & Brownell, S. E. (2021). Christianity as a concealable stigmatized identity (CSI) among biology graduate students. *CBE—Life Sciences Education*, *20*(1), ar9. https://doi.org/10.1187/cbe.20-09-0213

Barton, A. C., Tan, E., & Rivet, A. (2008). Creating hybrid spaces for engaging school science among urban middle school girls. *American Educational Research Journal*, *45*(1), 68–103. https://doi.org/10.3102/0002831207308641

Bayir, E., Cakici, Y., & Ertas, O. (2014). Exploring natural and social scientists' views of nature of science. *International Journal of Science Education*, *36*(8), 1286–1312. https://doi.org/10.1080/09500693.2013.860496

Bergquist, W. H., & Pawlak, K. (2008). *Engaging the six cultures of the academy* (2nd ed.). San Fransico, CA: Jossey-Bass.

Buxton, C. A. (2001). Modeling science teaching on science practice? Painting a more accurate picture through an ethnographic lab study. *Journal of Research in Science Teaching*, *38*(4), 387–407. https://doi.org/10.1002/tea.1011

Cao, C. (2014). The universal values of science and China's Nobel Prize pursuit. *Minerva*, *52*(2), 141–160. https://doi.org/10.1007/s11024-014-9249-y

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching*, *44*(8), 1187–1218. https://doi.org/10.1002/tea.20237

Carlone, H. B., & Johnson, A. (2012). Unpacking "culture" in cultural studies of science education: Cultural difference versus cultural production. *Ethnography and Education*, *7*(2), 151–173. https://doi.org/10.1080/17457823.2012.693691

Carrier, M. (2013). Values and objectivity in science: Value-ladenness, pluralism and the epistemic attitude. *Science & Education*, *22*(10), 2547–2568. https://doi.org/10.1007/s11191-012-9481-5

Clancy, K. B. H., Nelson, R. G., Rutherford, J. N., & Hinde, K. (2014). Survey of Academic Field Experiences (SAFE): Trainees report harassment and assault. *PLoS ONE*, *9*(7), e102172. https://doi.org/10.1371/journal.pone.0102172

Clemmons, A. W., Timbrook, J., Herron, J. C., & Crowe, A. J. (2020). BioSkills Guide: Development and national validation of a tool for interpreting the *Vision and Change* core competencies. *CBE—Life Sciences Education*, *19*(4), ar53. https://doi.org/10.1187/cbe.19-11-0259

Collins, H. (1982). Knowledge, norms, and rules in the sociology of science. *Social Studies of Science*, *12*(2), 299–309.

Collins, H. (1983). The sociology of scientific knowledge: Studies of contemporary science. *Annual Review of Sociology*, *9*(1), 265–285. https://doi.org/10.1146/annurev.so.09.080183.001405

Cooper, K. M., Cala, J. M., & Brownell, S. E. (2021). Cultural capital in undergraduate research: An exploration of how biology students operationalize knowledge to access research experiences at a large, public research-intensive institution. *International Journal of STEM Education*, *8*, ar6. https://doi.org/10.1186/s40594-020-00265-w

Cooper, K. M., Gin, L. E., Akeeh, B., Clark, C. E., Hunter, J. S., Roderick, T. B., … & Brownell, S. E. (2019). Factors that predict life sciences student persistence in undergraduate research experiences. *PLoS ONE*, *14*(8), e0220186. https://doi.org/10.1371/journal.pone.0220186

Costa, V. B. (1995). When science is "another world": Relationships between worlds of family, friends, school, and science. *Science Education*, *79*(3), 313–333. https://doi.org/10.1002/sce.3730790306

Djørup, S., & Kappel, K. (2013). The norm of disinterestedness in science; a restorative analysis. *SATS*, *14*(2), 153–175. https://doi.org/10.1515/sats-2013-0009

Douglas, H. (2000). Inductive risk and values in science. *Philosophy of Science*, *67*(4), 559–579. JSTOR.

Dunbar, K. (1995). How scientists really reason: Scientific reasoning in real-world laboratories. In Sternberg, R. J., & Davidson, J. (Eds.), *The nature of insight* (pp. 365–395). Cambridge, MA: MIT Press.

Dutt, K. (2020). Race and racism in the geosciences. *Nature Geoscience*, *13*(1), 2–3. https://doi.org/10.1038/s41561-019-0519-z

Elliot, K. C., & Resnik, D. B. (2014). Science, policy, and the transparency of values. *Environmental Health Perspectives*, *122*(7), 647–650. https://doi.org/10.1289/ehp.1408107

Erduran, S., & Dagher, Z. R. (2014a). Aims and values of science. In Erduran, S., & Dagher, Z. R. (Eds.), *Reconceptualizing the nature of science for science education: Scientific knowledge, practices and other family categories* (pp. 41–65). Dordrecht, Netherlands: Springer. https://doi.org/10.1007/978-94-017-9057-4_3

Erduran, S., & Dagher, Z. R. (2014b). Science as a social-institutional system. In Erduran, S., & Dagher, Z. R. (Ed.), *Reconceptualizing the nature of science for science education: Scientific knowledge, practices and other family categories* (pp. 137–162). Dordrecht, Netherlands: Springer. https://doi.org/10.1007/978-94-017-9057-4_7

Estrada, M., Woodcock, A., Hernandez, P. R., & Schultz, P. W. (2011). Toward a model of social influence that explains minority student integration into the scientific community. *Journal of Educational Psychology*, *103*(1), 206–222. https://doi.org/10.1037/a0020743

Evagorou, M., Erduran, S., & Mäntylä, T. (2015). The role of visual representations in scientific practices: From conceptual understanding and knowledge generation to "seeing" how science works. *International Journal of STEM Education*, *2*(1), 11. https://doi.org/10.1186/s40594-015-0024-x

Fink, A. (2005). *Conducting Research Literature Reviews: From the Internet to Paper*. Thousand Oaks, CA: Sage.

Frese, M. (2015). Cultural practices, norms, and values. *Journal of Cross-Cultural Psychology*, *46*(10), 1327–1330. https://doi.org/10.1177/0022022115600267

Fujimura, J. H. (1987). Constructing "do-able" problems in cancer research: Articulating alignment. *Social Studies of Science*, *17*(2), 257–293. https://doi.org/10.1177/030631287017002003

Gardner, G. E., Forrester, J. H., Jeffrey, P. S., Ferzli, M., & Shea, D. (2015). Authentic science research opportunities: How do undergraduate students begin integration into a science community of practice? *Journal of College Science Teaching*, *44*(4), 61–65.

Gooding, D. (1992). Putting agency back into experiment. In Pickering, A. (Ed.), *Science as practice and culture* (pp. 65). Chicago: University of Chicago Press.

Gough, D. (2004). Systematic research synthesis to inform the development of policy and practice in education. In Thomas, G., & Pring, R. (Eds.), *Evidenced-based practice* (pp. 44–62). London, England: Open University Press.

Gough, D. (2007). Weight of Evidence: A framework for the appraisal of the quality and relevance of evidence. *Research Papers in Education*, *22*(2), 213–228. https://doi.org/10.1080/02671520701296189

Gouvea, J., & Passmore, C. (2017). "Models of" versus "Models for." *Science & Education*, *26*(1), 49–63. https://doi.org/10.1007/s11191-017-9884-4

Hacking, I. (1992). The self-vindication of the laboratory sciences. In Pickering, A. (Ed.), *Science as practice and culture* (pp. 29–64). Chicago: University of Chicago Press.

Heinrich, S. (2020). Medical science faces the post-truth era: A plea for the grassroot values of science. *Current Opinion in Anesthesiology*, *33*(2), 198–202. https://doi.org/10.1097/ACO.0000000000000833

Hildebrand, G. M. (2007). Diversity, values and the science curriculum. In Corrigan, D., Dillon, J., & Gunstone, R. (Eds.), *The re-emergence of values in science education* (pp. 45–60). The Netherlands: Sense Publishers.

Hurtado, S., Cabrera, N. L., Lin, M. H., Arellano, L., & Espinosa, L. L. (2009). Diversifying science: Underrepresented student experiences in structured research programs. *Research in Higher Education*, *50*(2), 189–214. https://doi.org/10.1007/s11162-008-9114-7

Ibrahim, A., Aulls, M. W., & Shore, B. M. (2017). Teachers' roles, students' personalities, inquiry learning outcomes, and practices of science and engineering: The development and validation of the McGill Attainment Value for Inquiry Engagement survey in STEM disciplines. *International Journal of Science and Mathematics Education*, *15*(7), 1195–1215. https://doi.org/10.1007/s10763-016-9733-y

Irzik, G., & Nola, R. (2014). New directions for nature of science research. In In Matthews, M. R. (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 999–1021). Dordrecht, Netherlands: Springer. https://doi.org/10.1007/978-94-007-7654-8_30

Joshi, M., Aikens, M. L., & Dolan, E. L. (2019). Direct ties to a faculty mentor related to positive outcomes for undergraduate researchers. *BioScience*, *69*(5), 389–397. https://doi.org/10.1093/biosci/biz039

Kalelioglu, F., Gulbahar, Y., & Kukul, V. (2016). *A framework for computational thinking based on a systematic research review*. *Journal of Modern Computing*, *4*(3), 583–596.

Kalleberg, R. (2007). A reconstruction of the ethos of science. *Journal of Classical Sociology*, *7*(2), 137–160. https://doi.org/10.1177/1468795X07078033

Kieff, F. S. (2000). Facilitating scientific research: intellectual property rights and the norms of science—a response to Rai and Eisenberg Forum. *Northwestern University Law Review*, *2*, 691–706.

Knorr, K. D. (1977). Producing and reproducing knowledge: Descriptive or constructive? Toward a model of research production. *Information (International Social Science Council)*, *16*(6), 669–696. https://doi.org/10.1177/053901847701600602

Knorr-Cetina, K. D. (1982). Scientific communities or transepistemic arenas of research? A critique of quasi-economic models of science. *Social Studies of Science*, *12*(1), 101–130. https://doi.org/10.1177/030631282012001005

Knorr-Cetina, K. D. (1991). Merton's sociology of science: The first and the last sociology of science? *Contemporary Sociology*, *20*(4), 522–526. JSTOR. https://doi.org/10.2307/2071782

Koertge, N. (2005). *Scientific values and civic virtues*. New York: Oxford University Press.

Lacey, H. (1997). The constitutive values of science. *Principia: An International Journal of Epistemology*, *1*(1), 3–40.

Latour, B. (1999). *Pandora's hope: Essays on the reality of science studies*. Cambridge, MA: Harvard University Press.

Latour, B., & Woolgar, S. (1979). *Laboratory life: The construction of scientific facts*. Princeton, NJ: Sage.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, MA: Cambridge University Press.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, *39*(6), 497–521. https://doi.org/10.1002/tea.10034

Limeri, L. B., Asif, M. Z., Bridges, B. H. T., Esparza, D., Tuma, T. T., Sanders, D., … & Dolan, E. L. (2019). "Where's my mentor?!" Characterizing negative mentoring experiences in undergraduate life science research. *CBE—Life Sciences Education*, *18*(4), ar61. https://doi.org/10.1187/cbe.19-02-0036

Lopatto, D. (2004). Survey of Undergraduate Research Experiences (SURE): First findings. *Cell Biology Education*, *3*(4), 270–277. https://doi.org/10.1187/cbe.04-07-0045

Lopatto, D. (2009). *Science in solution: The impact of undergraduate research on student learning*. Quincy, MA: Research Corporation for Science Advancement.

Lunetta, V. N., Hofstein, A., & Clough, M. P. (2007). Learning and teaching in the school science laboratory: An analysis of research, theory and practice. In Abell, S. K., & Lederman, N. G. (Eds.), *Handbook of Research on Science Education*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc. (pp. 393–441).

Lynch, M. (1982). Technical work and critical inquiry: Investigations in a scientific laboratory. *Social Studies of Science*, *12*(4), 499–533. https://doi.org/10.1177/030631282012004002

Macfarlane, B., & Cheng, M. (2008). Communism, universalism and disinterestedness: Re-examining contemporary support among academics for Merton's scientific norms. *Journal of Academic Ethics*, *6*(1), 67–78. https://doi.org/10.1007/s10805-008-9055-y

Malinowski, B. (1960). *A scientific theory of culture and other essays*. New York, NY: Oxford University Press.

Mann, A. (2018). Sensory science research on taste. An ethnography of two laboratory experiments in Western Europe. *Food and Foodways*, *26*(1), 23–39. https://doi.org/10.1080/07409710.2017.1420352

McComas, W. F., & Olson, J. (2002). The nature of science in international science education standards documents. In McComas, W. F. (Ed.), *The nature of science in science education* (pp. 41–52). Dordrecht, Netherlands: Kluwer Academic. https://doi.org/10.1007/0-306-47215-5_2

Miranda, R. J., & Damico, J. B. (2013). Science teachers' beliefs about the influence of their summer research experiences on their pedagogical practices. *Journal of Science Teacher Education*, *24*(8), 1241–1261. https://doi.org/10.1007/s10972-012-9331-y

Mitroff, I. I. (1974). Norms and counter-norms in a select group of the Apollo moon scientists: A case study of the ambivalence of scientists. *American Sociological Review*, *39*(4), 579–595. JSTOR. https://doi.org/10.2307/2094423

Mody, C. C. M. (2015). Scientific practice and science education. *Science Education*, *99*(6), 1026–1032. https://doi.org/10.1002/sce.21190

Moore, F. M. (2007). Language in science education as a gatekeeper to learning, teaching, and professional development. *Journal of Science Teacher Education*, *18*(2), 319–343. JSTOR.

Mulkay, M. J. (1976). Norms and ideology in science. *Social Science Information*, *15*(4–5), 637–656. https://doi.org/10.1177/053901847601500406

Mulkay, M. J., & Gilbert, G. N. (1983). Scientists' theory talk. *Canadian Journal of Sociology/Cahiers Canadiens de Sociologie*, *8*(2), 179–197. https://doi.org/10.2307/3340125

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

Nersessian, N. J. (2006). The cognitive-cultural systems of the research laboratory. *Organization Studies*, *27*(1), 125–145.

Phelan, P., Davidson, A. L., & Cao, H. T. (1991). Students' multiple worlds: Negotiating the boundaries of family, peer, and school cultures. *Anthropology & Education Quarterly*, *22*(3), 224–250. https://doi.org/10.1525/aeq.1991.22.3.05x1051k

Pickering, A. (1992). *Science as practice and culture*. Chicago: University of Chicago Press.

Reinholz, D. L., Matz, R. L., Cole, R., & Apkarian, N. (2019). STEM is not a monolith: A preliminary analysis of variations in STEM disciplinary cultures and implications for change. *CBE—Life Sciences Education*, *18*(4), mr4. https://doi.org/10.1187/cbe.19-02-0038

Resnik, D. B. (2007). *The price of truth: How money affects the norms of science*. New York: Oxford University Press.

Restivo, S. P. (1994). *Science, society, and values: Toward a sociology of objectivity*. Cranbury, NJ: Lehigh University Press.

Rosenberg, J. F. (2008). Scientific values and the values of science. In Carrier, M., Howard, D., & Kourany, J. A. (Eds.), *The challenge of the social and the pressure of practice: Science and values revisited* (pp. 112–130). Pittsburgh, PA: University of Pittsburgh Press.

Sandoval, W. A., & Redman, E. H. (2015). The contextual nature of scientists' views of theories, experimentation, and their coordination. *Science & Education*, *24*(9), 1079–1102. https://doi.org/10.1007/s11191-015-9787-1

Schmaus, W. (1983). Fraud and the norms of science. *Science, Technology, & Human Values*, *8*(4), 12–22. https://doi.org/10.1177/016224398300800404

Schwartz, R., & Lederman, N. (2008). What scientists say: Scientists' views of nature of science and relation to science context. *International Journal of Science Education*, *30*(6), 727–771. https://doi.org/10.1080/09500690701225801

Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving: Why undergraduates leave the sciences*. Boulder, CO: Westview.

Shein, E. H. (2004). *Organizational culture and leadership* (3rd ed.). San Fransico, CA: Jossey-Bass.

Smokler, H. (1983). Institutional rationality: The complex norms of science. *Synthese*, *57*(2), 129–138. https://doi.org/10.1007/BF01063998

Stehr, N. (1978). The ethos of science revisited. *Sociological Inquiry*, *48*(3–4), 172–196. https://doi.org/10.1111/j.1475-682X.1978.tb00825.x

Taconis, R., & Kessels, U. (2009). How choosing science depends on students' individual fit to "science culture." *International Journal of Science Education*, *31*(8), 1115–1132. https://doi.org/10.1080/09500690802050876

Taras, V., Rowney, J., & Steel, P. (2009). Half a century of measuring culture: Review of approaches, challenges, and limitations based on the analysis of 121 instruments for quantifying culture. *Journal of International Management*, *15*(4), 357–373. https://doi.org/10.1016/j.intman.2008.08.005

Thiry, H., & Laursen, S. L. (2011). The role of student-advisor interactions in apprenticing undergraduate researchers into a scientific community of practice. *Journal of Science Education and Technology*, *20*(6), 771–784. https://doi.org/10.1007/s10956-010-9271-2

Thoman, D. B., Muragishi, G. A., & Smith, J. L. (2017). Research microcultures as socialization contexts for underrepresented science students. *Psychological Science*, *28*(6), 760–773. https://doi.org/10.1177/0956797617694865

Thompson, J. J., Conaway, E., & Dolan, E. L. (2016). Undergraduate students' development of social, cultural, and human capital in a networked research experience. *Cultural Studies of Science Education*, *11*(4), 959–990. https://doi.org/10.1007/s11422-014-9628-6

Thompson, J. J., & Jensen-Ryan, D. (2018). Becoming a "science person": Faculty recognition and the development of cultural capital in the context of undergraduate biology research. *CBE—Life Sciences Education*, *17*(4), ar62. https://doi.org/10.1187/cbe.17-11-0229

Traweek, S. (1993). Cultural differences in high-energy physics: Contrasts between Japan and the United States. In Harding, S. G. (Ed.), *The "racial" economy of science: Toward a democratic future*. Bloomington, IN: Indiana University Press. Retrieved July 2019, from http://login.ezproxy.lib.umn.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,uid&db=nlebk&AN=1265&site=ehost-live

Tuana, N. (2013). Embedding philosophers in the practices of science: Bringing humanities to the sciences. *Synthese*, *190*(11), 1955–1973. https://doi.org/10.1007/s11229-012-0171-2

Tweney, R. (2004). Replication and the Experimental ethnography of science. *Journal of Cognition and Culture*, *4*(3–4), 731–758. https://doi.org/10.1163/1568537042484968

van Aalderen-Smeets, S. I., van der Molen, J. H. W., & Asma, L. J. F. (2012). Primary teachers' attitudes toward science: A new theoretical framework. *Science Education*, *96*(1), 158–182. https://doi.org/10.1002/sce.20467

Velasco, J. B., Knedeisen, A., Xue, D., Vickrey, T. L., Abebe, M., & Stains, M. (2016). Characterizing instructional practices in the laboratory: The Laboratory Observation Protocol for Undergraduate STEM. *Journal of Chemical Education*, *93*(7), 1191–1203. https://doi.org/10.1021/acs.jchemed.6b00062

Wohlin, C. (2014). Guidelines for snowballing in systematic literature studies and a replication in software engineering. In *Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering* (article 38, pp. 1–10). New York: Association for Computing Machinery. https://doi.org/10.1145/2601248.2601268

Wohlin, C., Runeson, P., Höst, M., Ohlsson, M. C., Regnell, B., & Wesslén, A. (2012). Systematic literature reviews. In Wohlin, C., Runeson, P., Höst, M., Ohlsson, M. C., Regnell, B., & Wesslén, A. (Eds.), *Experimentation in software engineering* (pp. 45–54). Berlin, Germany: Springer. https://doi.org/10.1007/978-3-642-29044-2_4

Xiao, Y., & Watson, M. (2019). Guidance on conducting a systematic literature review. *Journal of Planning Education and Research*, *39*(1), 93–112. https://doi.org/10.1177/0739456X17723971

Yearley, S. (2004). *Making sense of science: Understanding the social study of science*. London, England: Sage.

Zeigler, D. (2009). Conveying the values of science and biology. *BioScience*, *59*(3), 198–199. https://doi.org/10.1525/bio.2009.59.3.2

Zenzen, M., & Restivo, S. (1982). The mysterious morphology of immiscible liquids: A study of scientific practice. *Information (International Social Science Council)*, *21*(3), 447–473. https://doi.org/10.1177/053901882021003004

Zhao, F., & Schuchardt, A. (2021). Development of the Sci-math Sensemaking Framework: Categorizing sensemaking of mathematical equations in science. *International Journal of STEM Education*, *8*(1), 10. https://doi.org/10.1186/s40594-020-00264-x