Supplemental Material

CBE—Life Sciences Education

Dewey *et al*.

Development of a Framework for the Culture of Scientific Research and Application to Course-based Undergraduate Research Experiences (Dewey et al.) – Supplemental Materials

Table S1: Details of the 78 manuscripts used to develop the CSR Framework

Table S2: Citations for the Practices of Scientific Research

Table S3: Citations for the Norms/Expectations of Scientific Research

Table S4: Citations for the Values/Beliefs of Scientific Research

Aspects of Biological Research Survey

Table S5: Proportion relevant by career stage

Table S6: Proportion relevant by discipline

Table S7: Proportion relevant by gender identity

Table S8: Proportion relevant by race/ethnicity

Table S9: Proportion relevant by institution type

Table S1: Details of the 78 manuscripts used to develop the CSR Framework. Full citations contained in the manuscript reference list

Authors	Year	Type	Summary
Mitroff	1974	Article	A study of scientists' conformity to Merton's norms which reveals potential counter-norms
Mulkay	1976	Article	Essay critiquing the norms and counter-norms of science
Knorr	1977	Article	Description of a model for scientific success and application of the model to data from a laboratory
Stehr	1978	Article	A critical examination of the normative structure of scientific practice. In this paper, the author uses the Mertonian norms to define the current status of this theory
Latour & Woolgar	1979	Book	A monograph about a **neuroendocrinology** lab at the Salk institute and how scientists in this lab work towards producing knowledge
Knorr-Cetina	1981	Article	Essay on how scientists produce knowledge, with a focus on constructionism and context-dependency
Collins	1982	Article	A response written to an article by Thomas Gieryn that describes the norms and rules in science as described through the sociology of science
Knorr-Cetina	1982	Article	Paper that critiques economic and social models of science and presents a model of science that is transepistemic
Law & Williams	1982	Article	Analysis of how scientists from **chemistry and biochemistry** negotiate how to write a paper in the most valuable way
Lynch	1982	Article	Analysis of a transcript to describe the process of critical inquiry in a **neuroscience** lab
Zenzen & Restivo	1982	Article	Account and discussion of 2 years of scientific work on the morphology of liquids in a **colloid chemistry lab**; focus on 'what happened' and the differences between three reported accounts of the work
Collins	1983	Article	Review of how the sociology of science (or scientific knowledge) has changed over time, the current methods being used, and implications of recent findings
Knorr-Cetina	1983	Article	Review and synthesis of 6 major studies of laboratory work using ethnographic methods. These studies were in various disciplines: **ecology, colloid chemistry, cell biology, molecular biology in plants, and neuroscience**
Mulkay & Gilbert	1983	Article	Recounting of how **biologists** talk about 'theory' in relation to their experimental work
Schmaus	1983	Article	An essay on the norms of science and how fraud and self-interestedness still persist and occur in science
Smokler	1983	Article	An essay on how the methodological rules the science is governed by are in turn affected by social practices which are governed by norms and rules
Lynch	1985	Book	Book describing an ethnography of a **neuroscience** laboratory where the author focuses on the social basis of the production of accounts in the research
Fujimura	1987	Article	Presents a framework for 'alignment' and how scientists use this idea to decide on do-able problems to pursue
Longino	1990	Book	Book describing the value-ladenness of science through analysis and examples of science in action

Collins	1992	Book	Book about replication and induction in science
Gooding	1992	Book chapter	Discussion of agency, specifically in the context of experimentation. Provides 4 properties of experimental practice
Hacking	1992	Book chapter	Overview of what laboratory sciences are and provides a taxonomy of 'experiment' in laboratory sciences
Mellican	1992	Article	A paper about fraud in science and how scientists respond to misconduct through the lens of scientific norms and practices
Traweek	1993	Book	Comparison of **high-energy physics labs** in Japan and the United States
Anderson & Louis	1994	Article	Paper exploring how doctoral students in **chemistry, civil engineering, microbiology, and sociology** are oriented to the norms of academic research
Restivo	1994	Book	Book exploring the sociology of science, the sociology of objectivity, and the connections between science, objectivity, and human values
Dunbar	1995	Article	Description of the cognitive and social processes that are part of scientific discovery and reasoning
Knorr-Cetina	1995	Book chapter	Review of studies within 'laboratory studies'; how they came to be, their findings, and future work to be done
Marks	1996	Article	An essay on science norms and behaviors and how they relate to the humanities and society
Lacey	1997	Article	Paper discussing constitutive values of science, namely which constitutive values should be included in the ‘list’ for science and whether they can be separated from more general values (e.g. social)
Allchin	1999	Article	An essay on values in science, specifically epistemic values and cultural values, and how they may be taught in schools
Lacey	1999	Article	Paper proposing six normative principles that guide the values and conduct of science
Latour	1999	Book	Book describing Latour’s thought on reality and how scientists go from practice to knowledge production
Rai	1999	Article	A paper describing the norms of science and how they changed as laws related to intellectual property rights and patents emerged
Douglas	2000	Article	Paper discussing how inductive risk leads to non-epistemic values being important when scientists make decisions and interpret data, with examples from **toxicology**
Kieff	2000	Article	A critique and response to previous work discussing how patents impacted the norms of science
Buxton	2001	Article	An ethnographic study of “Sally’s Lab” (**molecular biology**) where data on the daily practices of the lab members was collected and interpreted. Results were also connected to science education in K-12.
McComas & Olson	2002	Book chapter	Book chapter describing and comparing nature of science elements that are present in eight different standards documents for education

Schwartz et al.	2004	Article	Study examining potential changes in preservice secondary science teachers' understanding of the nature of science through their participation in a science research internship course
Tweney	2004	Article	Describing 'experimental ethnography' as an approach to understand scientific thinking
Yearley	2004	Book	Book discussing what makes science special and how it relates to the social sciences
Koertge	2005	Book	A book of essays comparing and relating the value of science to the values of a civil society
Nersessian	2006	Article	Discusses the integrated nature of cultural and cognitive aspects of science, specifically in the context of problem solving in a **biomedical engineering** lab
Hildebrand	2007	Book chapter	Book chapter discussing whose values (and voices) are used in the science curriculum and which values ought to be taught
Kalleberg	2007	Article	Paper discussing Merton's ideas about the ethos of science and how they still apply today, along with norms that Merton did not explicitly list
Resnik	2007	Book	A book about ethical responsibility and money in science
Artigas	2008	Book chapter	Book chapter describing the values inherent to science practice
Macfarlane & Cheng	2008	Article	Paper discussing three of Merton's norms in the context of today's science
Rosenberg	2008	Book chapter	Book chapter discussing different views of science and how they relate to scientific values (e.g. Baconian views, scientific realism, etc.)
Schwartz & Lederman	2008	Article	A study analyzing scientists' views of the nature of science and whether these views differed by discipline (**life sciences, earth and space science, chemistry, physics**)
Tuunainen & Knuuttila	2008	Article	This paper explores how the rules and norms of science at academic institutions are changed or impacted when business activities come into the picture
Zeigler	2009	Article	Essay about four fundamental values of science
Anderson et al.	2010	Article	Paper exploring scientists' subscription to the norms proposed by Merton and the counter norms proposed by Mitroff, while proposing four new norm-counter norm pairs. Participants were from **biomedical, clinical, biological, and behavioral sciences**
Ayar & Yalvac	2010	Article	Review of some ethnographic studies of science, identifying the cultural aspects of science that these studies identify which are not currently part of science education
AAAS	2011	Policy document	A policy document outlining goals for how undergraduate **biology** education should change and improve (Vision and Change)

Carrier	2013	Article	Paper discussing the nature of scientific objectivity and how values play a role in maintaining this objectivity in epistemic (or academic) research
Djørup & Kappel	2013	Article	A paper arguing for the applicability of the ‘disinterestedness’ norm to science
Mirando & Damico	2013	Article	A study exploring teacher’s beliefs about how participation in a research experience impacted their teaching practices
Tuana	2013	Article	A paper arguing for philosophy to be a discipline that works with science
Cao	2014	Article	Paper discussing the values of modern science and how science in **China** deviates from these values in the pursuit of Nobel Prize awards
Elliot & Resnik	2014	Article	A paper proposing principles for how scientists should communicate findings when they relate to policy
Erduran & Dagher	2014	Book chapter	Book chapter that discusses science as a social-institutional system and presents a framework for applying this view of science to educational contexts
Erduran & Dagher	2014	Book chapter	Book chapter reviewing the literature on the aims and values of science and relating them to science education
Irzik & Nola	2014	Book chapter	Book chapter discussing the Family Resemblance Approach to understanding the Nature of Science
Ayar et al.	2015	Article	This study is a meta-ethnography of three interpretive studies of science
Evagorou et al.	2015	Article	Paper arguing for the use of visual representations as epistemic objects when teaching science in order to emphasize how visualization adds to knowledge formation
Mody	2015	Article	Essay describing scientific practices beyond those in the lab (administrative, etc.) and how these should be incorporated into science education
Sandoval & Redman	2015	Article	A study exploring the contextual nature of scientists’ understanding about the nature of science
Gardner	2017	Article	A study exploring how students’ knowledge of the Nature of Science is impacted by curriculum that explicitly integrates knowledge from **biology and chemistry** in a laboratory context
Ibrahim et al.	2017	Article	Paper describing the development and validation of the McGill Attainment Value for Inquiry Engagement Survey (MAVIES) with undergraduate students
Lancaster et al.	2017	Article	An exploration of how pre-service teacher’s views of the nature of science might change through reflection and discussions with practicing scientists
Baze & Gray	2018	Article	Paper describing a model-based inquiry activity about **evolution** and its impact on undergraduate’s modeling abilities
Davidson & Hughes	2018	Article	Description of the patterns of interactions, common purpose, and communal resources of science from teacher's experiences as spectator novices in labs

Mann	2018	Article	An ethnography of two **sensory science** experiments in **European** labs studying flavor perception
Hessels et al.	2019	Article	Case study of four different science labs and how their epistemic cultures differ from each other
Meschitti	2019	Article	An ethnography of peer learning occurring between PhD students during group meetings in a **computer science** lab in **Switzerland**
Peffer & Ramezani	2019	Article	Study to compare novice and expert practices in science, specifically **biology,** to develop an assessment
Heinrich	2020	Article	Review describing how medical science has been fraught with fraud and other issues in recent years, and how returning to the original values of science may help

Table S2: Citations for the Practices of Scientific Research

Practices	References
Scientists pose questions, hypotheses, and predictions	Allchin, 1999; AAAS, 2011; Artigas, 2008; Ayar & Yalvac, 2010; Baze & Gray, 2018; Buxton, 2001; Dunbar, 1995; Elliot & Resnik, 2014; Erduran & Dagher, 2014a; Evagorou et al., 2015; Hacking, 1992; Ibrahim et al., 2017; Irzik & Nola, 2014; Lacey, 1997; Latour, 1999; Mann, 2018; Peffer & Ramezani, 2019; Restivo, 1994; Rosenberg, 2008; Schmaus, 1983; Tweney, 2004
Scientists plan investigations	Allchin, 1999; AAAS, 2011; Ayar & Yalvac, 2010; Buxton, 2001; Carrier, 2013; Douglas, 2000; Dunbar, 1995; Elliot & Resnik, 2014; Erduran & Dagher, 2014a; Evagorou et al., 2015; Fujimura, 1987; Hacking, 1992; Ibrahim et al., 2017; Irzik & Nola, 2014; Knorr-Cetina, 1982; Mann, 2018; Miranda & Damico, 2013; Restivo, 1994; Sandoval & Redman, 2015; Schmaus, 1983
Scientists run investigations	Allchin, 1999; AAAS, 2011; Artigas, 2008; Ayar et al., 2015; Ayar & Yalvac, 2010; Buxton, 2001; Carrier, 2013; Davidson & Hughes, 2018; Douglas, 2000; Erduran & Dagher, 2014a; Erduran & Dagher, 2014b; Evagorou et al., 2015; Fujimura, 1987; Gooding, 1992; Hacking, 1992; Hessels et al., 2019; Ibrahim et al., 2017; Irzik & Nola, 2014; Knorr-Cetina, 1995; Latour, 1999; Longino, 1990; Miranda & Damico, 2013; Mann, 2018; Mody, 2015; Peffer & Ramezani, 2019; Rosenberg, 2008; Schmaus, 1983; Tweney, 2004; Yearley, 2004
Scientists analyze data	Allchin, 1999; Ayar & Yalvac, 2010; Djørup & Kappel, 2013; Douglas, 2000; Erduran & Dagher, 2014a; Evagorou et al., 2015; Hacking, 1992; Hessels et al., 2019; Ibrahim et al., 2017; Irzik & Nola, 2014; Latour, 1999; Mann, 2018; Miranda & Damico, 2013; Restivo, 1994; Tuana, 2013
Scientists evaluate and interpret of data	Allchin, 1999; AAAS, 2011; Ayar et al., 2015; Buxton, 2001; Carrier, 2013; Douglas, 2000; Elliot & Resnik, 2014; Erduran & Dagher, 2014a; Erduran & Dagher, 2014b; Evagorou et al., 2015; Hacking, 1992; Ibrahim et al., 2017; Irzik & Nola, 2014; Knorr-Cetina, 1981; Koertge, 2005; Latour, 1999; Longino, 1990; Lynch, 1982; Mody, 2015; Restivo, 1994; Tweney, 2004; Yearley, 2004

Scientists generate arguments, explanations, and conclusions	Baze & Gray, 2018; Buxton, 2001; Carrier, 2013; Erduran & Dagher, 2014a; Evagorou et al., 2015; Ibrahim et al., 2017; Latour & Woolgar, 1979; Miranda & Damico, 2013; Mody, 2015; Peffer & Ramezani, 2019
Scientists negotiate and debate	Allchin, 1999; Ayar et al., 2015; Ayar & Yalvac, 2010; Baze & Gray, 2018; Carrier, 2013; Collins, 1983; Erduran & Dagher, 2014b; Evagorou et al., 2015; Hacking, 1992; Ibrahim et al., 2017; Kalleberg, 2007; Knorr-Cetina, 1995; Koertge, 2005; Latour, 1999; Latour & Woolgar, 1979; Marks, 1996; Meschitti, 2019; Miranda & Damico, 2013; Mody, 2015
Scientists produce and use representations of phenomena	Collins, 1983; Evagorou et al., 2015; Latour & Woolgar, 1979; Mody, 2015
Scientists develop and use models	AAAS, 2011; Baze & Gray, 2018; Carrier, 2013; Douglas, 2000; Evagorou et al., 2015; Hacking, 1992; Ibrahim et al., 2017; Irzik & Nola, 2014; Mann, 2018; Nersessian, 2006
Scientists apply and use computational approaches	AAAS, 2011; Evagorou et al., 2015; Ibrahim et al., 2017; Mann, 2018; Miranda & Damico, 2013; Restivo, 1994; Tuana, 2013
Scientists obtain and evaluate information	Davidson & Hughes, 2018; Evagorou et al., 2015; Hacking, 1992; Ibrahim et al., 2017; Irzik & Nola, 2014; Meschitti, 2019; Miranda & Damico, 2013; Mody, 2015; Peffer & Ramezani, 2019
Scientists communicate	Anderson et al., 2010; Ayar et al., 2015; Ayar & Yalvac, 2010; Cao, 2014; Davidson & Hughes, 2018; Djørup & Kappel, 2013; Elliot & Resnik, 2014; Erduran & Dagher, 2014a; Erduran & Dagher, 2014b; Evagorou et al., 2015; Gardner, 2017; Hacking, 1992; Ibrahim et al., 2017; Irzik & Nola, 2014; Kalleberg, 2007; Koertge, 2005; Lancaster et al., 2017; Mann, 2018; Marks, 1996; McComas & Olson, 2002; Meschitti, 2019; Miranda & Damico, 2013; Mody, 2015; Schmaus, 1983; Tuunainen & Knuuttila, 2008; Tweney, 2004

Scientists work in teams	Baze & Gray, 2018; Dunbar, 1995; Erduran & Dagher, 2014b; Evagorou et al., 2015; Hessels et al., 2019; Irzik & Nola, 2014; Knorr-Cetina, 1982; Meschitti, 2019; Miranda & Damico, 2013; Mody, 2015; Zenzen & Restivo, 1982

Table S3: Citations for the Norms/Expectations of Scientific Research

Norms/Expectations	References
Scientists aims to be objective, but are influenced by their prior knowledge and beliefs	Allchin, 1999; Anderson et al., 2010; Anderson & Louis, 1994; Artigas, 2008; Ayar & Yalvac, 2010; Cao, 2014; Carrier, 2013; Collins, 1982; Djørup & Kappel, 2013; Douglas, 2000; Elliot & Resnik, 2014; Erduran & Dagher, 2014a; Erduran & Dagher, 2014b; Gardner, 2017; Hildebrand, 2007; Irzik & Nola, 2014; Kalleberg, 2007; Kieff, 2000; Knorr-Cetina, 1995; Koertge, 2005; Lacey, 1999; Longino, 1990; Lynch, 1985; Macfarlane & Cheng, 2008; Marks, 1996; McComas & Olson, 2002; Mellican, 1992; Mitroff, 1974; Mulkay, 1976; Mulkay & Gilbert, 1983; Resnik, 2007; Restivo, 1994; Sandoval & Redman, 2015; Schmaus, 1983; Schwartz & Lederman, 2008; Smokler, 1983; Stehr, 1978; Tuana, 2013; Tuunainen & Knuuttila, 2008; Yearley, 2004
Science aims for integrity	Allchin, 1999; Anderson et al., 2010; Anderson & Louis, 1994; Artigas, 2008; Ayar & Yalvac, 2010; Baze & Gray, 2018; Buxton, 2001; Cao, 2014; Carrier, 2013; Collins, 1982, 1983; Djørup & Kappel, 2013; Douglas, 2000; Elliot & Resnik, 2014; Erduran & Dagher, 2014a; Erduran & Dagher, 2014b; Heinrich, 2020; Hildebrand, 2007; Irzik & Nola, 2014; Kalleberg, 2007; Kieff, 2000; Koertge, 2005; Lacey, 1997; Latour, 1999; Latour & Woolgar, 1979; Longino, 1990; Macfarlane & Cheng, 2008; Mann, 2018; Marks, 1996; McComas & Olson, 2002; Mellican, 1992; Mitroff, 1974; Mody, 2015; Mulkay, 1976; Mulkay & Gilbert, 1983; Rai, 1999; Resnik, 2007; Restivo, 1994; Rosenberg, 2008; Schmaus, 1983; Smokler, 1983; Stehr, 1978; Tuunainen & Knuuttila, 2008; Tweney, 2004; Yearley, 2004; Zeigler, 2009; Zenzen & Restivo, 1982
Scientific work should be repeated or repeatable	Allchin, 1999; Buxton, 2001; Carrier, 2013; Collins, 1982, 1983, 1992; Davidson & Hughes, 2018; Erduran & Dagher, 2014a; Heinrich, 2020: Irzik & Nola, 2014; Longino, 1990; Mellican, 1992; McComas & Olson, 2002; Miranda & Damico, 2013; Rosenberg, 2008; Tweney, 2004
Scientific work is often peer reviewed	Allchin, 1999; Anderson et al., 2010; Ayar & Yalvac, 2010; Cao, 2014; Irzik & Nola, 2014; Knorr, 1977; Knorr-Cetina, 1982; Longino, 1990; McComas & Olson, 2002; Mellican, 1992; Mody, 2015; Smokler, 1983

Scientists must publish their work as a measure of success, often leading to competition	Anderson et al., 2010; Artigas, 2008; Ayar et al., 2015; Ayar & Yalvac, 2010; Buxton, 2001; Carrier, 2013; Cao, 2014; Djørup & Kappel, 2013; Erduran & Dagher, 2014a; Erduran & Dagher, 2014b; Hessels et al., 2019; Hilldebrand, 2007; Irzik & Nola, 2014; Kalleberg, 2007; Knorr, 1977; Knorr-Cetina, 1982; Koertge, 2005; Lacey, 1997, 1999; Law & Williams, 1982; Macfarlane & Cheng, 2008; Marks, 1996; M. J. Mulkay, 1976; Rai, 1999; Resnik, 2007; Restivo, 1994; Rosenberg, 2008; Schmaus, 1983; Traweek, 1993; Yearley, 2004
Science is often collaborative	Allchin, 1999; AAAS, 2011; Ayar & Yalvac, 2010; Baze & Gray, 2018; Buxton, 2001; Cao, 2014; Carrier, 2013; Davidson & Hughes, 2018; Erduran & Dagher, 2014b; Gardner, 2017; Hildebrand, 2007; Irzik & Nola, 2014; Kalleberg, 2007; Knorr-Cetina, 1982, 1983; Koertge, 2005; Lancaster et al., 2017; Latour, 1999; Longino, 1990; Lynch, 1982, 1985; Mann, 2018; McComas & Olson, 2002; Mody, 2015; Rai, 1999; Restivo, 1994; Sandoval & Redman, 2015; Zeigler, 2009
Scientists should have freedom and independence	Anderson et al., 2010; Anderson & Louis, 1994; Ayar et al., 2015; Buxton, 2001; Cao, 2014; Erduran & Dagher, 2014b; Fujimura, 1987; Hessels et al., 2019; Irzik & Nola, 2014; Kieff, 2000; Koertge, 2005; Lacey, 1997; Lynch, 1985; Macfarlane & Cheng, 2008; McComas & Olson, 2002; M. J. Mulkay, 1976; Nersessian, 2006; Rai, 1999; Resnik, 2007; Restivo, 1994; Sandoval & Redman, 2015; Smokler, 1983; Stehr, 1978; Traweek, 1993; Tuana, 2013; Yearley, 2004; Zenzen & Restivo, 1982
Scientists must be persistent and resilient	Ayar et al., 2015; Collins, 1983; Davidson & Hughes, 2018; Evagorou et al., 2015; Miranda & Damico, 2013; Tweney, 2004; Zenzen & Restivo, 1982
Scientists must be open to new ideas	Allchin, 1999; Anderson & Louis, 1994; Anderson et al., 2010; Cao, 2014; Collins, 1982; Djørup & Kappel, 2013; Dunbar, 1995; Erduran & Dagher, 2014b; Gooding, 1992; Irzik & Nola, 2014; Kalleberg, 2007; Kieff, 2000; Koertge, 2005; Lynch, 1982; Macfarlane & Cheng, 2008; Marks, 1996; McComas & Olson, 2002; Mellican, 1992; Mitroff, 1974; M. J. Mulkay, 1976; Schmaus, 1983; Smokler, 1983; Stehr, 1978; Tuunainen & Knuuttila, 2008; Yearley, 2004; Zeigler, 2009

Table S4: Citations for the Values/Beliefs of Scientific Research

Values/Beliefs	References
Science is defined by a desire to discover new knowledge about the natural world	Allchin, 1999; Anderson et al., 2010; Anderson & Louis, 1994; Artigas, 2008; Ayar et al., 2015; Ayar & Yalvac, 2010; Cao, 2014; Carrier, 2013; Collins, 1982; Davidson & Hughes, 2018; Djørup & Kappel, 2013; Heinrich, 2020; Irzik & Nola, 2014; Kalleberg, 2007; Kieff, 2000; Koertge, 2005; Lacey, 1997; Macfarlane & Cheng, 2008; Marks, 1996; McComas & Olson, 2002; Mellican, 1992; Mitroff, 1974; Mulkay, 1976; Rai, 1999; Rosenberg, 2008; Sandoval & Reman, 2015; Schmaus, 1983; Smokler, 1983; Stehr, 1978; Tuunainen & Knuuttila, 2008; Yearley, 2004; Zeigler, 2009
Science is defined by its requirement for empirical evidence	Ayar & Yalvac, 2010; Carrier, 2013; Gardner, 2017; Irzik & Nola, 2014; Koertge, 2005; Lacey, 1997; McComas & Olson, 2002; Resnik, 2007; Sandoval & Redman, 2015; Schwartz & Lederman, 2008; Schwartz et al., 2004
Science is not all-knowing	Allchin, 1999; Ayar & Yalvac, 2010; Cao, 2014; Davidson & Hughes, 2018; Kalleberg, 2007; Lancaster et al., 2017; McComas & Olson, 2002; Mulkay, 1976
Science is defined by the production of durable but tentative knowledge	Ayar & Yalvac, 2010; Gardner, 2017; Irzik & Nola, 2014; Lancaster et al., 2017; Marks, 1996; McComas & Olson, 2002; Rosenberg, 2008; Sandoval & Redman, 2015; Schwartz & Lederman, 2008; Schwartz et al., 2004
Science places importance on curiosity, imagination, and creativity	Artigas, 2008; Ayar & Yalvac, 2010; Davidson & Hughes, 2018; Gardner, 2017; Hildebrand, 2007; Irzik & Nola, 2014; Koertge 2005; Lancaster et al., 2017; McComas & Olson, 2002; Schwartz & Lederman, 2008; Schwartz et al., 2004; Zeigler, 2009
Science is defined by the use of a variety of methods	Ault & Dodick, 2010; Carrier, 2013; Gardner, 2017; Irzik & Nola, 2014; Lacey, 1999; McComas & Olson, 2002; Sandoval & Redman, 2015

Science is influenced by and contributes to society and culture	Allchin, 1999; Artigas, 2008; Ayar & Yalvac, 2010; Cao, 2014; Carrier, 2013; Davidson & Hughes, 2018; Djørup & Kappel, 2013; Erduran & Dagher, 2014a; Erduran & Dagher, 2014b; Gardner, 2017; Hessels et al., 2019; Irzik & Nola, 2014; Knorr-Cetina, 1983; Lacey, 1999; Mann, 2018; McComas & Olson, 2002; Sandoval & Redman, 2015; Schmaus, 1983; Schwartz & Lederman, 2008; Schwartz et al., 2004; Smokler, 1983; Tuana, 2013; Tweney, 2004
Science builds on what has gone before	Ayar et al., 2015; Knorr, 1977; Knorr-Cetina, 1981, 1982; McComas & Olson, 2002; Sandoval & Redman, 2015
Science is defined as constructive and complex	Ayar et al., 2015; Carrier, 2013; Erduran & Dagher, 2014a; Gooding, 1992; Hildebrand, 2007; Knorr-Cetina, 1981, 1983; Lacey, 1997; Latour, 1999; Rodenberg, 2008; Sandoval & Redman, 2015

Aspects of Biological Research Survey

In which field(s) have you participated in the process of biological research? Check all that apply

- ☐ Ecology
- ☐ Evolution
- ☐ Animal Behavior
- ☐ Molecular biology
- ☐ Cell biology
- ☐ Developmental biology
- ☐ Biochemistry
- ☐ Genetics
- ☐ Plant biology
- ☐ Microbial biology
- ☐ Computational biology
- ☐ Other (please specify below) ______________________________

What is your career stage?

- ○ Graduate student
- ○ Postdoctoral researcher
- ○ Assistant Professor
- ○ Associate Professor
- ○ Professor
- ○ Other (please specify below) ____

Do you currently participate in the process of biological research?

- ○ Yes
- ○ No

Display This Question:

If Do you currently participate in the process of biological research? = Yes

How many years have you been participating in the process of biology research?

- ○ 0-2 years
- ○ 3-5 years
- ○ 6-10 years
- ○ 10+ years

Display This Question:

If Do you currently participate in the process of biological research? = No

How many years has it been since you participated in the process of biological research?

- ○ 0-2 years
- ○ 3-5 years
- ○ 6-10 years
- ○ 10+ years

Display This Question:

If Do you currently participate in the process of biological research? = No

For how many years did you participate in the process of biological research?

- ○ 0-2 years
- ○ 3-5 years
- ○ 6-10 years
- ○ 10+ years

Thinking over the entirety of your career as a biological researcher, which of the following aspects have been relevant to your experience(s)?

	Relevant	Not relevant
Biological research is often collaborative	○	○
Biological researchers should be open to new ideas	○	○
Biological researchers run investigations	○	○
Biological research involves the discovery of new knowledge	○	○
Biological investigations should be repeated or repeatable	○	○
Biological research involves curiosity, imagination, and creativity	○	○
Biological researchers generate arguments, explanations, and conclusions	○	○
Biological knowledge is durable but subject to change	○	○
Biological researchers communicate results and new knowledge to others	○	○
Biological research cannot answer all questions	○	○

Thinking over the entirety of your career as a biological researcher, which of the following aspects have been relevant to your experience(s)?

	Relevant	Not relevant
Biological research is influenced by and contributes to society and culture	○	○
Biological researchers plan investigations	○	○
Biological researchers aim to be objective, but their prior knowledge and beliefs can impact the research	○	○
Biological researchers analyze data	○	○
Biological researchers pose questions, hypotheses, and predictions	○	○
Biological researchers read carefully, so pick Not Relevant for this aspect	○	○
Biological researchers aim for integrity in their work	○	○
Biological researchers apply and use computational approaches	○	○
Biological researchers must be persistent and resilient, because encountering difficulties is normal	○	○
Biological researchers obtain and evaluate information	○	○
Biological researchers must publish their work as a measure of success, often leading to competition	○	○

Thinking over the entirety of your career as a biological researcher, which of the following aspects have been relevant to your experience(s)?

	Relevant	Not relevant
Biological research is constructive and complex	○	○
Biological researchers develop and use models	○	○
Biological research involves academic freedom and independence	○	○
Biological research requires empirical evidence	○	○
Biological researchers evaluate and interpret data	○	○
Biological investigations can use a variety of methods	○	○
Biological researchers often work together in teams	○	○
Biological research builds on what has gone before	○	○
Biological researchers produce and use representations	○	○
Biological research is often peer reviewed	○	○
Biological researchers negotiate and debate	○	○

Q25 Do you have any comments to share about deciding whether the aspects were relevant or not to your experiences?

____

____

____

____

____

Q10 If there are any other aspects that have been relevant to your experience(s) as a biological researcher, please list them below:

____

____

____

____

____

To ensure we have diverse identities represented in our data, we are collecting demographic information regarding your gender identity, race/ethnicity, and institution type.

Do you identify as transgender?

- ○ Yes
- ○ No
- ○ Prefer not to disclose

What gender do you identify with? Check all that apply

- [ ] Woman
- [ ] Man
- [ ] Non-binary
- [ ] Agender
- [ ] Gender non-conforming
- [ ] Genderfluid
- [ ] Prefer not to disclose
- [ ] Category/identity not listed above (please specify below)

____

What race and/or ethnicities do you identify with? Check all that apply

- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Middle Eastern or North African
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ White (of Hispanic, Latino, or Spanish origin)
- ☐ White (not of Hispanic, Latino, or Spanish origin)
- ☐ Multiethnic
- ☐ Prefer not to disclose
- ☐ Race and/or ethnicity not listed above (please specify below)

____

What type of institution are you associated with? Check all that apply

- ☐ Community College
- ☐ Primarily undergraduate-serving institution (PUI)
- ☐ Minority-serving institution (HBCU, HSI, etc.)
- ☐ R1 doctorate-granting university
- ☐ R2 or R3 doctorate-granting university
- ☐ Masters-granting university
- ☐ Other (please specify below) ____

Table S5: Proportion relevant by career stage

Category	Aspect	Career Stage					
		Graduate Student (n=51)	Post Doc (n=19)	Assistant Prof (n=23)	Associate Prof (n=20)	Professor (n=22)	Other (n=26)
Practices	Pose questions	98%	100%	100%	100%	100%	100%
	Plan investigations	100%	95%	100%	95%	100%	96%
	Run investigations	88%	79%	100%	90%	100%	96%
	Analyze data	100%	100%	100%	100%	100%	96%
	Evaluate and interpret data	100%	100%	100%	100%	100%	100%
	Generate arguments, explanations, conclusions	94%	95%	100%	95%	100%	100%
	Negotiate and debate	77%	68%	78%	85%	77%	92%
	Produce representations	86%	74%	91%	95%	77%	85%
	Develop and use models	92%	100%	96%	95%	91%	92%
	Computational approaches	88%	90%	91%	85%	91%	89%
	Obtain and evaluate info	100%	100%	100%	100%	96%	100%
	Communication	94%	100%	100%	100%	100%	100%
	Teamwork	90%	100%	100%	95%	100%	100%
Norms/ Expectations	Objectivity	96%	95%	91%	95%	96%	100%
	Integrity	98%	95%	96%	100%	100%	100%
	Repeat investigations	92%	100%	96%	100%	100%	96%
	Peer reviewed	100%	100%	100%	100%	100%	96%
	Publish as success	86%	95%	87%	85%	82%	85%
	Collaborative	94%	95%	100%	100%	100%	96%
	Freedom and independence	73%	90%	87%	95%	91%	73%
	Persistent and resilient	96%	95%	100%	95%	96%	100%
	Open to new ideas	98%	100%	100%	100%	100%	100%
Values/ Beliefs	Discovery	94%	100%	100%	100%	100%	96%
	Empirical evidence	90%	100%	96%	100%	96%	92%
	Cannot answer all questions	90%	100%	96%	90%	91%	89%
	Durable but subject to change	94%	84%	100%	100%	100%	100%
	Curiosity/imagination	90%	100%	100%	100%	100%	100%
	Variety of methods	98%	100%	96%	100%	100%	100%
	Influence by/contributes to society	88%	90%	83%	80%	100%	100%
	Builds on what has gone before	98%	100%	100%	100%	100%	100%
	Constructive and complex	98%	100%	100%	90%	96%	100%

Table S5 note: The ‘Other’ category includes career positions such as lecturers, staff, lab managers or coordinators, and people who are in-between positions or left academia

Table S6: Proportion relevant by discipline

Category	Aspect	Discipline						
		EEB (n=122)	MCDBG (n=58)	Biochem (n=12)	PlantMicro (n=48)	Comp (n=13)	Neuro (n=7)	Other (n=26)
Practices	Pose questions	100%	100%	100%	100%	100%	100%	96%
	Plan investigations	98%	98%	100%	100%	100%	100%	100%
	Run investigations	91%	93%	92%	92%	100%	100%	92%
	Analyze data	100%	100%	100%	98%	100%	100%	100%
	Evaluate and interpret data	100%	100%	100%	100%	100%	100%	100%
	Generate arguments, explanations, conclusions	97%	98%	92%	100%	100%	86%	100%
	Negotiate and debate	76%	79%	83%	75%	77%	86%	81%
	Produce representations	82%	88%	92%	88%	85%	86%	96%
	Develop and use models	92%	97%	83%	92%	100%	100%	96%
	Computational approaches	92%	90%	100%	90%	100%	86%	85%
	Obtain and evaluate info	99%	100%	100%	100%	92%	100%	100%
	Communication	98%	97%	100%	98%	100%	100%	100%
	Teamwork	95%	95%	100%	94%	100%	100%	100%
Norms/ Expectations	Objectivity	95%	98%	100%	96%	85%	100%	92%
	Integrity	98%	97%	100%	98%	100%	100%	100%
	Repeat investigations	95%	100%	100%	98%	100%	100%	100%
	Peer reviewed	99%	100%	100%	100%	100%	100%	96%
	Publish as success	84%	88%	92%	85%	92%	86%	92%
	Collaborative	96%	97%	100%	98%	100%	100%	92%
	Freedom and independence	79%	86%	92%	88%	85%	86%	85%
	Persistent and resilient	96%	97%	92%	98%	92%	100%	96%
	Open to new ideas	99%	98%	100%	98%	100%	100%	100%
Values/ Beliefs	Discovery	98%	97%	100%	98%	100%	100%	92%
	Empirical evidence	93%	98%	100%	96%	100%	100%	92%
	Cannot answer all questions	92%	95%	92%	94%	92%	86%	92%
	Durable but subject to change	95%	95%	100%	98%	100%	100%	100%
	Curiosity/imagination	96%	95%	100%	96%	100%	100%	96%
	Variety of methods	100%	97%	100%	98%	100%	100%	100%
	Influence by/contributes to society	89%	91%	100%	92%	100%	86%	92%

	Builds on what has gone before	99%	100%	100%	100%	100%	100%	100%
	Constructive and complex	97%	98%	100%	98%	100%	100%	100%

Table S6 Note: Survey respondents were given the option to choose multiple subdisciplines that applied to their biological research. To summarize these data, broad categories of subdisciplines were defined: Ecology, Evolution, and Behavior (EEB); Molecular, Cellular, Developmental Biology, and Genetics (MCDBG); Biochemistry (Biochem); Plant and Microbial Biology (PlantMicro); Computational Biology (Comp); Neuroscience (Neuro). Respondents who chose subdisciplines included in multiples categories are represented multiple times in this table. The ‘Other’ category includes more specific subdisciplines entered by survey participants such as immunology, forestry, and biology education.

Table S7: Proportion relevant by gender identity

Category	Aspect	Gender identity					
		Woman (n=101)	Man (n=48)	Nonbinary (n=4)	Transgender (n=2)	Genderfluid/ Nonconforming (n=2)	Not disclosed (n=4)
Practices	Pose questions	99%	100%	100%	100%	100%	100%
	Plan investigations	97%	100%	100%	100%	100%	100%
	Run investigations	90%	98%	75%	100%	50%	100%
	Analyze data	99%	100%	100%	100%	100%	100%
	Evaluate and interpret data	100%	100%	100%	100%	100%	100%
	Generate arguments, explanations, conclusions	97%	98%	75%	100%	100%	100%
	Negotiate and debate	77%	83%	100%	50%	50%	100%
	Produce representations	86%	83%	75%	100%	50%	100%
	Develop and use models	95%	90%	100%	100%	100%	100%
	Computational approaches	88%	90%	100%	100%	100%	75%
	Obtain and evaluate info	100%	98%	100%	100%	100%	100%
	Communication	100%	98%	50%	100%	100%	100%
	Teamwork	96%	96%	100%	100%	100%	100%
Norms/ Expectations	Objectivity	95%	96%	100%	100%	100%	100%
	Integrity	98%	98%	100%	100%	100%	100%
	Repeat investigations	96%	96%	100%	100%	100%	100%
	Peer reviewed	99%	100%	100%	100%	100%	100%
	Publish as success	83%	90%	100%	100%	100%	100%
	Collaborative	97%	96%	100%	100%	100%	100%
	Freedom and independence	80%	88%	50%	100%	50%	100%
	Persistent and resilient	96%	98%	100%	100%	100%	100%
	Open to new ideas	100%	98%	100%	100%	100%	100%
Values/ Beliefs	Discovery	97%	98%	100%	100%	100%	100%
	Empirical evidence	97%	92%	75%	50%	100%	100%
	Cannot answer all questions	89%	96%	100%	100%	100%	100%
	Durable but subject to change	95%	98%	100%	100%	100%	100%
	Curiosity/imagination	97%	98%	75%	100%	100%	100%
	Variety of methods	98%	100%	100%	100%	100%	100%
	Influence by/contributes to society	89%	92%	100%	100%	100%	75%
	Builds on what has gone before	99%	100%	100%	100%	100%	100%
	Constructive and complex	98%	96%	100%	100%	100%	100%

Table S8: Proportion relevant by Race/Ethnicity

Category	Aspect	Race/Ethnicity					
		White (n=130)	Latinx (n=10)	Asian (n=6)	Black (n=1)	Multi-racial/ethnic (n=7)	Not disclosed (n=7)
Practices	Pose questions	99%	100%	100%	100%	100%	100%
	Plan investigations	98%	100%	100%	100%	100%	100%
	Run investigations	91%	100%	100%	100%	86%	100%
	Analyze data	99%	100%	100%	100%	100%	100%
	Evaluate and interpret data	100%	100%	100%	100%	100%	100%
	Generate arguments, explanations, conclusions	96%	100%	100%	100%	100%	100%
	Negotiate and debate	80%	70%	83%	100%	71%	86%
	Produce representations	84%	90%	100%	100%	71%	100%
	Develop and use models	94%	80%	100%	100%	100%	100%
	Computational approaches	92%	70%	100%	100%	57%	86%
	Obtain and evaluate info	99%	100%	100%	100%	100%	100%
	Communication	98%	100%	100%	100%	100%	100%
	Teamwork	97%	90%	100%	100%	86%	100%
Norms/ Expectations	Objectivity	95%	100%	100%	100%	100%	100%
	Integrity	99%	100%	100%	100%	86%	100%
	Repeat investigations	95%	100%	100%	100%	100%	100%
	Peer reviewed	100%	90%	100%	100%	100%	100%
	Publish as success	86%	80%	83%	100%	86%	100%
	Collaborative	98%	100%	83%	100%	86%	100%
	Freedom and independence	81%	100%	100%	100%	57%	100%
	Persistent and resilient	97%	100%	83%	100%	100%	100%
	Open to new ideas	99%	100%	100%	100%	100%	100%
Values/ Beliefs	Discovery	98%	90%	100%	100%	100%	100%
	Empirical evidence	94%	100%	100%	100%	86%	100%
	Cannot answer all questions	92%	90%	100%	100%	100%	86%
	Durable but subject to change	97%	90%	100%	100%	86%	100%
	Curiosity/imagination	96%	100%	100%	100%	100%	100%
	Variety of methods	99%	100%	100%	100%	100%	100%
	Influence by/contributes to society	90%	100%	83%	100%	86%	86%
	Builds on what has gone before	99%	100%	100%	100%	100%	100%
	Constructive and complex	97%	100%	100%	100%	100%	100%

Table S9: Proportion relevant by institution type

Category	Aspect	Institution Type						
		R1 (n=81)	R2/R3 (n=34)	PUI (n=16)	Masters (n=6)	MSI (n=2)	Two or more (n=15)	Other (n=7)
Practices	Pose questions	100%	97%	100%	100%	100%	100%	100%
	Plan investigations	98%	97%	100%	100%	100%	100%	100%
	Run investigations	91%	88%	100%	67%	100%	100%	100%
	Analyze data	100%	100%	100%	100%	100%	93%	100%
	Evaluate and interpret data	100%	100%	100%	100%	100%	100%	100%
	Generate arguments, explanations, conclusions	95%	97%	100%	100%	100%	100%	100%
	Negotiate and debate	77%	82%	94%	17%	50%	100%	86%
	Produce representations	84%	79%	94%	83%	100%	93%	86%
	Develop and use models	94%	94%	94%	100%	100%	93%	86%
	Computational approaches	93%	82%	88%	83%	100%	87%	86%
	Obtain and evaluate info	99%	100%	100%	100%	100%	100%	100%
	Communication	98%	97%	100%	100%	100%	100%	100%
	Teamwork	94%	100%	100%	83%	100%	100%	100%
Norms/ Expectations	Objectivity	96%	91%	100%	83%	100%	100%	100%
	Integrity	98%	100%	100%	100%	50%	100%	100%
	Repeat investigations	95%	97%	94%	100%	100%	100%	100%
	Peer reviewed	100%	100%	100%	100%	100%	100%	86%
	Publish as success	85%	94%	88%	67%	50%	87%	85%
	Collaborative	95%	100%	100%	100%	100%	100%	86%
	Freedom and independence	77%	82%	94%	100%	50%	100%	71%
	Persistent and resilient	96%	94%	100%	100%	100%	100%	100%
	Open to new ideas	99%	100%	100%	100%	100%	100%	100%
Values/ Beliefs	Discovery	98%	97%	100%	100%	100%	100%	86%
	Empirical evidence	95%	94%	100%	83%	100%	100%	71%
	Cannot answer all questions	91%	91%	94%	100%	100%	93%	86%
	Durable but subject to change	95%	97%	100%	83%	100%	100%	100%
	Curiosity/imagination	94%	100%	100%	100%	100%	100%	100%
	Variety of methods	98%	100%	100%	100%	100%	100%	100%
	Influence by/contributes to society	90%	82%	100%	83%	100%	93%	100%
	Builds on what has gone before	99%	100%	100%	100%	100%	100%	100%
	Constructive and complex	98%	97%	100%	83%	100%	100%	100%

Table S9 Note: PUI = Primarily Undergraduate Institution; MSI = Minority-Serving Institution. The 'Other' category includes institutions such as government research labs or non-profits