Experiences of Transformative Awe and the "Small Self" in Scientific Learning and Discovery

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Experiences of Transformative Awe and the “Small Self” in Scientific Learning and Discovery

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A Thesis Presented to the Faculty of the Graduate School of Education of Harvard University in Partial Fulfillment of the Requirements for the Degree of Doctor of Education

2019
For Spud.
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Abstract

Over the past two decades, psychologists have found increasing evidence that experiencing the emotion of awe can facilitate a shift in perspective that reorients the individual toward contexts that are vastly greater than the self. For science educators who wish to help learners understand humans as participants within a variety of vast, interconnected systems, these findings suggest compelling implications about the potential of awe as a pedagogical tool. However, the existing research on awe is almost exclusively focused on adults, has been primarily conducted through laboratory studies that do not resemble authentic learning experiences, and has not specifically examined the relationship between awe and science.

In this dissertation, I present the findings of two qualitative studies that aim to further our understanding of the relationship between the emotion of awe, the experience of feeling connected to something larger than the self, and science learning. In Study 1, I interviewed professional scientists (n=30) to identify features of moments of awe that are experienced in the context of their scientific work and investigate the cognitive, affective, and behavioral impact of these experiences. The findings indicate that scientists’ experiences of awe resulted from personal moments of discovery as well as broader conceptual knowledge. Participants reported that awe served as a key motivator for their continued pursuit of the work.

In Study 2, I followed adolescent students (n=12) in two summer science programs to investigate how the instruction informed their perceived relationship to the large scientific phenomena and systems they were studying. Through analysis of observational and interview data and students’ written work, I found interactions between
the unique features of each setting and students’ orientation toward the scientific concepts addressed by the instruction. Across both sites, students reflected on how the instruction had shaped their understanding of natural systems, though they were less likely to extend their reflections to implications for their own roles and behaviors within those systems.

In addition to contributing to the scholarly literature, the findings from this dissertation offer implications for science pedagogy in the K-12 context as well as in higher education and the training of professional scientists.
Section 1

Chapter 1 | Dissertation Overview

There is a nearly universal phenomenon reported by astronauts who have traveled far enough away to view earth in its entirety from space: the experience seems to result in a powerful shift in their understanding of humans’ place on earth and earth’s place in the universe. From orbit, geopolitical borders are mostly imperceptible; instead, atmosphere, land, and sea are tangled together in one tiny sphere, suspended against the sharp background of black space. The resulting perspective shift, which has received significant attention from journalists and scholars, is known as the overview effect (White, 1987).

Though astronauts describe a broad range of sensations, two features of the overview effect emerge consistently: 1) it involves an intense, visceral reaction that is typically described as the emotion of awe, and 2) it seems to be transformative, in the sense that this perspective shift influences astronauts’ everyday experiences and behaviors long after they have returned from orbit (Yaden et al., 2016). In interviews and written reflections (e.g., Garan, 2015; White, 1987), astronauts who have experienced the overview effect regularly express deepened convictions about the human responsibility to care for each other and for the planet, and a number have even assumed roles as advocates for environmental protection, international cooperation, and other humanitarian efforts (White, 1987). As described by the Apollo 14 astronaut Edgar Mitchell, “You develop an instant global consciousness, a people orientation, an intense dissatisfaction with the state of the world, and a compulsion to do something about it” (People Staff, 1974).
While most of us will never find ourselves in orbit, the overview effect can serve as a metaphor to guide a broader exploration of transformative, awe-inspiring experiences that convey a sense that we are a part of something larger than ourselves. Indeed, over the past two decades, psychologists have found increasing evidence to support the notion that experiences of awe play a role in orienting us toward the wellbeing of the collective (e.g., Piff et al., 2015). Moreover, recent research suggests that the emotion of awe may facilitate learning in general, and scientific learning in particular (Valdesolo, Shtulman, & Baron, 2017). Such findings have compelling pedagogical implications for science educators who seek to frame instruction in a way that underscores the role of humans as participants within a variety of vast, complex, and interconnected systems.

Building on this existing research, this dissertation investigates the potential of awe as a tool for spurring science learners to think differently about their position within broader natural contexts. The dissertation consists of two qualitative studies: one that examines the experiences of professional scientists and one that investigates the learning trajectories of adolescents in two summer science programs. Together, these studies aim to further our understanding of how awe manifests in authentic settings of scientific learning and discovery.

This dissertation is divided into three sections, which are subdivided into chapters. In the remainder of this section (Chapter 2), I provide an introduction of the conceptual framework that guides this dissertation. The second section presents each individual study in turn. Chapter 3 is dedicated to the study of professional scientists. I begin with a more detailed overview of the relevant literature on awe experiences in science, present the methodology and findings, and offer study-specific conclusions.
Chapter 4 is dedicated to the study of adolescent science learners. I first present the theoretical frameworks that guided the study design and analysis, describe the methodological approach employed in the study, and provide descriptions of each of the two sites; I then present findings that emerged for each site individually and across the two sites and offer study-specific conclusions. The third section (Chapter 5) provides a synthesis of the two studies. I offer a broader set of conclusions, suggest implications for theory and practice, and propose directions for future research.
Chapter 2 | Conceptual Framework

The design of this dissertation was primarily motivated by theoretical and empirical scholarship from the social sciences on the emotion of awe. Until recently, however, the study of awe was not within the purview of psychologists. In this chapter, I situate the theoretical constructs that inform these dissertation studies within the broader interdisciplinary history of scholarship on awe as well as the burgeoning field of awe research in psychology and education.

The History of Scholarship on Awe

Historically, theologians and philosophers were the primary scholars of awe experiences. Notably, the 18th century philosopher Edmund Burke’s examination of the sublime has significant overlap with our current understanding of awe. Burke (1757/1990) posited that sublime experiences were evoked by stimuli with the properties of power and obscurity – properties similar to those current researchers have suggested are necessary for eliciting awe (Keltner & Haidt, 2003). Additionally, several prominent 19th century sociologists studied the role that awe played in contributing to power dynamics and the social order (e.g., Durkheim, 1887/1972; Weber, 1978).

One early treatment of awe in psychology came from Abraham Maslow, who addressed the emotion in his study of peak experiences (Maslow, 1964). In particular, some of the features of peak experiences proposed by Maslow (1964) – such as disorientation, transcendence, reverence, and humility – appear in many current definitions of awe. More recently, several psychologists (e.g., Ekman, 1992; Izard, 1977; Lazarus, 1991) posited that awe should be considered a discrete emotion, though their proposed definitions were not informed by empirical research.
The first comprehensive study of awe from a cognitive perspective came from the psychologists Dacher Keltner and Jonathan Haidt in 2003, and their definition remains the prevailing conception of awe in the current literature. Keltner and Haidt (2003) proposed a cognitive model consisting of two key features: the *perception of vastness* and the *need for accommodation*. Vastness often refers to physical size, but it can also refer to other scales such as time, complexity, or power. Accommodation refers to the notion that when new information does not fit within a learner’s existing schema, the learner must modify the schema or develop a new one (Piaget & Inhelder, 1969). According to Keltner and Haidt’s (2003) definition, both of these conditions are necessary for the emotion to qualify as awe; in other words, the individual must experience the perception of physical or symbolic vastness, as well as a violation of expectations that prompts her to seek a modification to her current understanding.

Other researchers have since elaborated on, or deviated from, this definition of awe. For instance, Bonner and Friedman (2011) propose a set of additional features beyond vastness and accommodation that include profoundness, connectedness, and existential awareness. Schneider (2017) has argued that awe, by definition, cannot involve accommodation; instead, the experience of awe “must be lived with, often for long periods of time, without the hope of being solved or comfortably categorized” (Schneider, 2017, p. 3). To some extent, Schinkel (2017) agrees with Schneider, suggesting that awe is a state in which we are simply humble or reverent toward the unknown; Schinkel also distinguishes between awe and several different types of wonder, including *deep wonder*, in which we are struck by a vivid awareness of that which is unknowable, and *active wonder*, in which we are driven to explore (which may in fact be
closest to Keltner and Haidt’s (2003) conception of awe). A number of researchers have also distinguished between awe and curiosity, typically making the claim that curiosity, while related to awe, is characterized by diminished intensity and usually does not involve a focus on the “big questions” (e.g., Quinn, 2002).

For the purposes of this dissertation, I rely primarily on Keltner and Haidt’s (2003) presumption that the individual experiencing awe has the possibility of deepening his or her understanding in the given context to some extent, even if some amount of information remains beyond the grasp of human knowledge. However, as I discuss further in Section 2 of the dissertation, I remain open to additional features of awe beyond those identified by Keltner and Haidt (2003) as experienced and articulated by the study participants. In the remainder of this chapter, I elaborate on the recent psychological research on awe and the existing evidence for a relationship between awe, science learning, and an orientation to the collective.

**The Epistemic and Collective Dimensions of Awe**

**The Role of Awe in Facilitating Science Learning**

Awe has been classified as an *epistemic emotion*, or an emotion involved in the process of knowledge acquisition (Morton, 2010; Schindler et al., 2017). Awe is differentiated from other epistemic emotions by its tendency to provoke the learner to revise his or her existing mental model. Rowen (2006) argues that this experience of disruption followed by accommodation means that “the condition of being in awe plays an important unsung role in the learning process” (p. 216).

Researchers have posited that awe may be an especially powerful emotion for facilitating science learning (e.g., Valdesolo, Shtulman, & Baron, 2016). The first
component of awe, perception of vastness, is a logical fit for science, given that scientific
corcepts often involve extreme magnitudes of scale (whether in space, time, quantity, or
complexity).\textsuperscript{1} Moreover, as science learning often involves expectation violation and
conceptual change, awe is potentially valuable in its capacity to motivate accommodation
(Valdesolo, Shtulman, & Baron, 2016).

Research indicates that people who are more dispositionally prone to experiencing
awe tend to have a higher tolerance for uncertainty and a greater openness to new
experiences (Shiota, Keltner, & John, 2006; Silvia, Fayn, Nusbaum, & Beaty, 2015).
Recently, psychologists have begun to investigate whether these tendencies are
associated with a willingness to embrace a scientific worldview. In a series of six studies,
Gottlieb, Keltner, and Lombrozo (2018) found a relationship between higher
dispositional awe and a more accurate understanding of the nature of science; the authors
speculate that a general tendency toward open-mindedness may translate into a
willingness to weigh competing explanatory models and consider new evidence.

Anecdotally, many scientists have frequently described experiencing awe through
their work, as I will discuss further in Chapter 3. However, the scholarship exploring the
link between awe and science has been primarily theoretical rather than grounded in
genuine lived experience. The closest that empirical research has come to investigating
awe in scientific contexts has been through the use of nature-related stimuli to evoke awe.
Several studies have used nature-based stimuli, both in lab-based settings (Weinstein,
Przybylski, & Ryan, 2009; Zelenski, Dopko, & Capaldi, 2015) and in informal learning
environments such as national parks and nature museums (Bai et al., 2017; Pennisi,
\textsuperscript{1} Indeed, “scale, proportion, and quantity” is one of seven crosscutting concepts identified in the Next
Lackey, and Holland, 2017). These studies have found evidence that exposure to nature is associated with increased feelings of connectedness to nature and intentions to engage in pro-environmental or other prosocial behaviors. More recently, McPhetres (2019) found that participants who viewed nature-based virtual reality videos used as a stimulus to elicit awe demonstrated an increased awareness of gaps in their knowledge about the natural world and, to a lesser extent, greater science interest (as measured by participants’ decision to select tickets to a science museum versus an art museum). However, these studies do not specifically address the disciplinary aspects of science, nor do they examine whether a broader range of experiences in science may have similar effects or may elicit a sense of connectedness that extends beyond nature (for instance, connectedness to humanity, to the cosmos, etc.).

The Potential Broader Impact of Awe Experiences

In addition to its identification as an epistemic emotion, researchers often classify awe as a collective emotion, noting that the experience of awe seems to draw one’s attention to matters beyond the self (Bai et al., 2017). In several studies analyzing individuals’ descriptions of awe experiences, one of the most prevalent themes is a positioning of the self as connected to something larger and more significant (Bonner & Friedman, 2011; Darbor et al., 2016). This orientation, which is referred to in the literature as “small self,” seems to “enable individuals to fold into collaborative social groups, and engage in collective action” (Piff et al., 2015, p. 883). In a series of studies, Shiota, Keltner, and Mossman (2007) asked participants to provide self-descriptions by writing 20 responses to the question “Who am I?”. In one experiment, people with higher levels of dispositional awe were more likely than those with lower levels to define
themselves through terms that emphasized “membership in a universal group” (e.g., “I am an inhabitant of the Earth”); in another, people who were primed to feel awe via a museum exhibition were more likely to use these universal self-descriptors than those who were placed in a neutral hallway.

Beyond simply influencing the self-concept, empirical research suggests that the mechanism of small self encourages people to behave in ways that go against their own self-interest to benefit the welfare of the collective. In comparison to participants in other conditions, individuals primed to feel awe have expressed more willingness to volunteer their time, donate hypothetical lottery winnings to charity, or help a stranger pick up spilled items (Piff et al., 2015; Prade & Saroglou, 2016). As noted above, studies of awe elicited by nature have also found evidence of a heightened sense of connectedness to the natural world that corresponds to greater inclinations toward pro-environmental behaviors. However, less is known about the impact of awe and small self outside of controlled experimental environments. Moreover, the existing studies have not invited participants to reflect on how their awe experiences have influenced their thinking or behavior. It is not yet clear whether individuals who experience awe in one setting are likely to apply any corresponding prosocial intuitions to a different setting down the road.

**Transformative Awe Experiences**

The process of applying one’s understanding to prior or future contexts is referred to as transfer, and has been studied in depth by educational researchers (e.g., Barnett & Ceci, 2002; Engle et al., 2012; Perkins & Salomon, 1988). Effective transfer requires deep understanding of a concept as well as the ability to recognize opportunities to connect this understanding to one’s prior knowledge and/or future experiences (Chi &
Van Lehn, 2012). If the initial framing of the concept is too narrow, the learner may not be able to recognize its potential for application to other contexts, whereas framing a concept expansively can “extend it to include the past and the future, different places, and additional people” (Engle et al., 2012, p. 218). Studies of K-12 science classrooms (e.g., Engle, 2006; Engle, Meyer, Clark, White, & Mendelson, 2010) have shown that students successfully transfer their knowledge to new situations when the teacher uses expansive framing strategies, such as helping students connect to prior and future learning contexts and “positioning students as part of a larger learning community” (Engle et al., 2012, p. 219).

Perkins, Jay and Tishman (1993) have proposed a triadic disposition theory of thinking which argues that effective transfer requires the learner to be sensitive to occasions to apply their understanding, capable of making the appropriate connections, and sufficiently inclined or motivated to do so. Though transfer is a pedagogical challenge, the literature provides a number of well-established strategies for facilitating the process. For instance, Perkins and Salomon (1988) suggest techniques of “hugging” and “bridging.” “Hugging” refers to teaching in ways that resemble and emphasize the conditions in which transfer might occur, while “bridging” involves explicitly pointing out opportunities for transfer or cuing students to look for such opportunities themselves.

Building on the notion of transfer, Mezirow used the phrase “transformative learning” to refer to the process by which an individual reflects upon, resolves, and integrates an initially “disorienting” learning experience such that it can be effectively applied in future contexts (Mezirow, 1995, p. 50). Pugh (2002; 2011) has defined a transformative experience in science as one that enables learners to apply their
understanding to a new context, see an aspect of the world anew through the lens of the experience, and feel that what has been learned is pragmatically useful and intrinsically meaningful.

Research from cognitive development and neuroscience has underscored that transformative learning is facilitated by emotional engagement (Immordino-Yang & Damasio, 2007; Taylor, 2001). Immordino-Yang and Damasio (2007) argue that emotions support transfer by “direct[ing] our reasoning into the sector of knowledge that is relevant to the current situation or problem” (p. 125). However, emotionally evocative pedagogical strategies must be designed thoughtfully to support learning rather than disrupt it. For instance, while King et al. (2015) have found that “emotionally intense” science activities are more likely to deeply engage the learner and facilitate recall, Harp and Mayer (1998) caution that students can be pulled into the “seductive details” of dramatic narratives that make it challenging to identify and recall important underlying principles. Moreover, while many typical science lessons involve flashy “demos” that capture the learners’ attention through surprise and delight, researchers have noted that such emotions are fleeting, and unlikely to have long-lasting impact if the instruction moves on too quickly and “does not allow students to persist in these emotions” (D’Mello & Graesser, 2011, p. 1301). The literature on discrepant events supports the notion that students should be given sufficient time to process and reflect on surprising phenomena and to pursue the questions that arise as a result of such surprising observations (Liem, 1981).

Researchers have suggested that evoking the emotion of awe may be especially effective at helping learners recognize contexts to apply their understanding and motivate
further discovery, given that awe tends to have a more lingering effect than other, less strong emotions (Bianchi, 2014; D’Mello & Graesser, 2011). Pugh, Bergstrom, and Spencer (2017) concur that approaches designed to conjure a sense of awe are especially well-aligned with the goals of transformative engagement in science. Of course, designing instructional activities that elicit awe and provoke transformative engagement is a pedagogical challenge. Thus, one goal of this dissertation was to collect and analyze the features of transformative experiences of awe in science, as described by scientists and demonstrated by students.

**Gaps Addressed by This Dissertation**

Given the apparent alignment between awe and science, as well as the tendency of awe to direct one’s attention to the collective, transformative awe experiences in science could plausibly help learners orient themselves to their role within broader natural systems. However, this idea has yet to be explored substantively in the research literature. In what follows, I offer three directions in which I have designed this dissertation to extend the existing research on awe, with the ultimate goal of identifying pedagogical implications for science education.

**Investigating Awe Experiences through the Disciplinary Lens of Science**

As previously noted, several studies have used nature-based stimuli for evoking awe, both in lab-based settings (Weinstein, Przybylski, & Ryan, 2009; Zelenski, Dopko, & Capaldi, 2015) and in informal learning environments such as national parks and nature museums (Bai et al., 2017; Pennisi, Lackey, & Holland, 2017). These studies have found evidence that exposure to nature is associated with increased feelings of connectedness to nature and intentions to engage in pro-environmental or other prosocial
behaviors. However, these studies do not specifically address the disciplinary aspects of science, nor do they examine whether a broader range of experiences in science may have similar effects or may elicit a sense of connectedness that extends beyond nature (for instance, connectedness to humanity, to the cosmos, etc.). In this dissertation, I investigate individuals’ experiences of awe elicited in scientific contexts that extend beyond exposure to nature.

**Including the Experiences of Younger Learners**

While most of the pedagogical recommendations in the literature have focused on K-12 education, the relevant research is almost exclusively focused on adults. The literature that does focus on younger individuals is mostly theoretical in nature (e.g., Halstead & Halstead, 2004). In this dissertation, I provide structures for adult participants to reflect critically on their childhood experiences of awe (Study 1) and I also study school-aged participants directly (Study 2).

**Utilizing Qualitative Approaches to Examine Authentic Experiences Over Time**

Finally, as some researchers have themselves acknowledged, the tightly controlled, lab-based nature of most of the existing studies inhibits our ability to explore the ways in which awe experiences manifest in more authentic contexts, as well as the nature of any longer-term effects that may extend beyond the initial moment of experience. In his commentary on “mainstream” approaches to awe, Schneider (2017) argues that the prevailing empirical approaches are “based on a narrow and objectivizing methodology” which “may yield commensurately narrow and transient results” (p. 2). This methodological approach, Schneider claims, limits our ability to explore the features of what he refers to as the “slow simmer variety of awe,” which entails “experiences that
are cultivated through persistent engagements, complicated relationships, and unsettling perceptions” (Schneider, 2017, p. 4). In this dissertation, I complement the existing experimental research with studies that take a qualitative approach to investigate the nuance and complexity of participants’ lived experiences.

In the section that follows, I present two studies that were designed to speak to these gaps in the literature though the participants, settings and contexts, and methodologies chosen. In the first study (Chapter 3), I interviewed 30 professional scientists across a range of fields and sectors about their encounters with awe in the context of science, from their earliest childhood experiences with science to their current professional work. The findings offer a more nuanced definition of the emotion of awe in the context of science and reveal some common themes in the ways that scientists perceive the personal and professional impacts of their awe experiences, including a motivational element that has not been the focus of prior literature. In the second study (Chapter 4), I followed a total of 12 adolescent (late high school and early college) students in two different six-week summer science programs (one lab-based course focused on genetics and biotechnology and one lecture-based course focused on cosmic evolution). At each site, I interviewed students, observed class sessions, and analyzed written work to investigate how, and to what extent, the programs were facilitating students’ understanding of their relationship to the vast and/or complex scientific phenomena they were studying. By examining the two learning contexts side by side, the findings reveal some of the affordances and challenges of the instructional approaches at each site and illuminate what is possible when students are invited to reflect on their personal relationship to scientific concepts and practices. It is my hope that these two
studies will contribute to our understanding of the nature of awe experiences in the context of scientific learning and discovery and will build on prior lab-based research to offer more concrete implications for practice.
Section 2

Chapter 3 | Study 1: Scientists’ Experiences of Transformative Awe

Introduction

In Chapter 1, I introduced the overview effect as an example of the impact of awe in the context of scientific discovery. Observing the earth from space is an especially powerful, and perhaps hard to rival, elicitor of awe. However, there are many anecdotes from a diverse range of scientists about the role awe has played in their work. For instance, the naturalist John Muir, who founded the Sierra Club and campaigned for the establishment of national parks, noted that his cognition and perception had been impacted by the immersive experience of looking out over grandiose mountain ranges as well as his deepening understanding of geologic time (Cohen, 1984; Fuller, 2006). Similarly, the environmentalist Rachel Carson commented on the experience of perceiving the world “in the long vistas of geologic time,” remarking, “perhaps if we reversed the telescope and looked at humans down these long vistas, we should find less time and inclination to plan for our own destruction” (Brooks, 1972, p. 127).

Awe experiences and their corresponding effects are not reserved for scientists who study large spatial and temporal scales; similar testimony exists from those who work at the molecular or atomic level (contexts which, as Keltner and Haidt might argue, typically involve a perception of vastness in number and complexity). For instance, the cell biologist Ursula Goodenough argued that a pursuit of science that is not grounded in awe and wonder is insufficient for establishing the “planetary ethic” necessary to sustain modern human life (Goodenough, 1998, p. 11).
When asked to describe the events that led to their pursuit of science, many scientists recall emotionally evocative moments from their childhoods. For instance, after winning the Nobel Prize for the discovery of RNA interference, the biologist Craig Mello wrote a narrative of his scientific career that focused on emotionally salient aspects of the journey (Mello, 2006). Early in the narrative, he recalls a childhood memory of playing in a local creek, turning over stones and searching for wildlife, when he suddenly witnessed a teenage driver on the nearby road intentionally swerve to hit a box turtle. Mello connects this memory to his current perspective and broader purpose as a scientist:

That morning of my youth seems timeless now. I can see in my heart that the child playing in the creek is me, and that I haven’t changed much really in the intervening years. I’m still turning over stones, hoping to find something new. I’m still struggling to understand what drives us humans to cruelty and hoping that knowledge of our place in the world can help us to achieve a higher purpose.

Examples like these suggest that scientists’ experiences of awe may involve not only the feeling of being connected to something greater than the self, but also an imperative to apply this understanding to one’s own life. More broadly, they present science as a human endeavor that is full of emotional resonance. Regrettably, this is not how science is typically taught in schools or communicated to the public. Through this study, I wish to make the case that a systematic collection and analysis of scientists’ narratives about the emotional elements of their work will contribute to our theoretical understanding of the nature of science as well as practical applications for science education and the institution of science more broadly.

**The Value of Drawing on Scientific Expertise for K-12 Learning Contexts**

The learning objectives introduced in Chapters 1 and 2 regarding students’ understanding of their relationship to natural phenomena are well documented in the
current national curriculum standards. Across the K-12 grade span, the Next Generation Science Standards (NGSS) address the notion that humans are a part of a large, complex system and that our behavior impacts that system (NGSS Lead States, 2013). For instance, one item under the heading of “Earth and Human Activity” at the K-2 level reads, “Things that people do to live comfortably can affect the world around them. But they can make choices that reduce their impacts on the land, water, air, and other living things” (NGSS Lead States, 2013, p. 7). Moreover, the Nature of Science dimension of the NGSS acknowledges that the process of interpreting and making choices based on scientific information “involves ethics, values, and human decisions about the use of knowledge” (NGSS Lead States, 2013, p. 434).

However, a number of education researchers have expressed concern that science teachers lack sufficient guidance to successfully teach about the nature of science (e.g., McComas & Nouri, 2016). Lederman and Lederman (2014) observe that this dimension of the NGSS is “buried” in an appendix and has therefore received a “lack of instructional attention” (p. 236). McComas and Nouri (2016) note that science teachers typically do not receive much exposure to content about the nature of science in pre-service or in-service teacher education. They lament that the NGSS includes very little concrete information about how to incorporate ideas about the human dimensions of science into the curriculum, and posit that experts could likely propose “far more engaging ways” to address these topics than the limited suggestions currently included in the NGSS (McComas & Nouri, 2016, p. 574).

Consulting disciplinary experts to guide K-12 content benchmarks is a common practice, and was heavily utilized in the development of the content knowledge aspects of
the NGSS (NGSS Lead States, 2013). Now, it appears that a parallel perspective is needed to guide instruction regarding the ways in which humans interpret and act on that knowledge. In this study, I take a step toward gathering this perspective through an investigation of the perceived impact of scientists’ awe experiences in the context of their work.

**Research Questions**

This study was designed with three primary aims: 1) to identify a set of features characterizing moments of awe that are experienced in the context of scientific work, 2) to investigate the cognitive, affective, and behavioral impact of these experiences as perceived by the participants, and 3) to analyze how the perceived impact develops over time as the participants process and reflect on their experiences. The study was guided by the following research questions:

1) What are some prevalent features of awe experiences in the context of science?

2) In what ways, if at all, do scientists see their awe experiences as transformative or otherwise impactful?

3) In what ways, if at all, do scientists report on awe experiences that evoke a sense of “small self” and/or its associated prosocial implications?

**Methods**

This study employs a qualitative methodology to investigate moments of awe in the context of science, as experienced by professional scientists. Specifically, the design draws on a phenomenological approach, which is based on the epistemological assumption that investigating how individuals experience and make meaning of a concept
or phenomenon can help us understand the “essence” of that concept or phenomenon (Polkinghorne, 1989; Moustakas, 1994).

Sample

The sample for this study consisted of professional scientists (n=30; female=13, male=17)² recruited using a purposeful sampling method that made use of existing academic and professional connections and a snowball sampling approach. The inclusion criteria were limited to individuals who possessed a doctoral degree in the natural sciences and were currently working in a science-related profession (academic or non-academic) at the time of the interview. For sampling purposes, I relied on the definition of natural science posited by Ledoux (2002): “natural sciences are defined as disciplines that deal only with natural events (i.e., independent and dependent variables in nature) using scientific methods” (p. 34). This definition enabled me to make decisions about whether to include potential participants whose expertise lay at the boundaries of another discipline, such as engineering, computer science, or the social sciences. For instance, in determining whether to include an individual with a doctoral degree in engineering, the study of fluid dynamics would qualify, whereas the study of bridge building would not.

Within these inclusion constraints, I sought to sample for maximum variation (Patton, 2015) in several dimensions, including field of expertise, length of expertise, and demographic diversity. Given the importance of vastness in the prototypical definition of awe (Keltner & Haidt, 2003), a priority in the recruiting process was to include individuals who work across a diversity of spatial and temporal scales. The participants’ institutional affiliations represented 20 different organizations across a variety of sectors. The primary institutional affiliation for 24 of the participants was with a college or

² This sample size is within the range deemed appropriate for phenomenological inquiry (Polkinghorne, 1989).
university (14 different academic institutions in total), while the remaining participants worked in industry, government, K-12 education, or independent research organizations. Four participants were working outside of the United States at the time of the interview.

Capturing a diversity of length of expertise was the biggest sampling challenge; in the sample, the length of time since earning one’s Ph.D. ranged from one month to 49 years, but the median length of time was 5.5 years. This is likely a product of the professional networks to which I had access as a young scholar myself. I have chosen to represent participants by the year they earned their Ph.D., both because I did not collect ages or other demographic data and because it tends to mark one’s transition to independent scholarship in the field. However, it is important to note that Ph.D. year does not directly correspond to the age of the participants, as a number of participants took time to pursue other work (typically related to their scientific field of study) in between their undergraduate and graduate degrees. A list of participants is provided in Table 1.

3 I also observed that scientists in the middle stage of their career were less likely to respond to a “cold” email requesting an interview than scientists at earlier and later stages. I do not have data to indicate reasons for this, but anecdotally, young scientists in my sample often expressed an inclination to help a peer, while the elder (tenured or retired) scientists seemed to have more flexibility in their schedules and expressed a motivation to share knowledge with a future generation of scholars. It is reasonable to speculate that mid-career scientists may feel particularly inclined to guard their time against threats to productivity, especially considering the findings in this paper regarding the constraints and pressures of science as an institution.
Table 1

*Study Participants’ Field of Expertise, Current Professional Affiliation, and Degree Year*

<table>
<thead>
<tr>
<th>Pseudonym</th>
<th>Field</th>
<th>Affiliation</th>
<th>Year Ph.D. Granted</th>
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<tr>
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<td>Andrew</td>
<td>Plant ecology</td>
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<td>Clara</td>
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<td>Ian</td>
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<td>Richard</td>
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</table>

**Data Collection Procedure**

Each participant was interviewed one time in a semi-structured interview lasting approximately one hour. Interviews were conducted in-person for local participants and
via video conferencing platforms for non-local participants. All interviews were audio-recorded and transcribed.

Though I conducted only one interview with each participant, I drew on Seidman’s (2006) three-interview series for in-depth, phenomenological interviewing as a general guide for designing the interview protocol. Thus, I began with life history questions, asking participants to construct a narrative about their journey into their scientific career. I then turned to the participants’ lived experiences regarding the focal topics of the study, asking them to reconstruct the details of moments of awe that they had experienced in their work. Finally, I asked them to “reflect on the meaning of their experience[s]” and to “address the intellectual and emotional connections between the participants’ work and life” (Seidman, 2006, p. 18). As an additional tool to facilitate reflection, I showed participants a short video clip (approximately four minutes) from the film Overview and asked them to discuss whether and how the testimony from astronauts and scholars in the film resonated with their own experiences with awe in science. The interview protocol is included in Appendix A.

**Data Analysis Procedure**

I conducted a thematic analysis of the data using the software tool MAXQDA (VERBI Software, 2012). To conduct the analysis, I used an iterative process that employed a blended approach of emic and etic coding strategies. I relied primarily on a data-driven approach, searching for “codable moments” (Boyatzis, 1998) and identifying themes that emerged from the text. During this first round of coding, I also coded for several concepts that are integral to the theoretical framing of awe based on the existing

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*Overview* is a film about the overview effect, the well-documented cognitive shift that astronauts experience upon seeing earth from space. The video can be found at [https://vimeo.com/55073825](https://vimeo.com/55073825). In the case of one interview, the nature of the technology set-up used for our video conference did not enable the participant to view the video, so I summarized the concept verbally instead.
literature, including the concepts of “perception of vastness” and “need for accommodation” that are the components of Keltner and Haidt’s (2003) prototypical definition.

As part of the analysis process, I recruited a second coder who is well-versed in qualitative analysis but is not an expert in the theoretical framing of my research to code a subset of the data (approximately 20% of the full sample) in order to “cast a wider analytic net and provide a ‘reality check’” (Saldaña, 2009, p. 27). The second coder and I independently wrote a thematic memo for each of the interviews we both coded, and then used these documents to guide conversations about the themes we each identified. This approach enabled the identification of additional themes and led to the clarification of the definitions and inclusion/exclusion criteria of existing themes. From this process, I developed a codebook, which I applied to the full dataset, though I remained open to adding new codes if additional themes emerged throughout the process. A codebook representing the most commonly used codes in the analysis can be found in Appendix B.

Following this analysis, participants were sent a draft summary of the findings. Participants were invited to comment on the specific interpretations of their own interview data and/or to offer reflections about the overall findings. This process served as a form of member check to assess “how accurately participants’ realities have been represented in the final account” (Creswell & Miller, 2000, p.125). A number of participants responded to confirm that they felt correctly represented by my interpretations and to offer general reactions to the findings (e.g., several said they were surprised that their feelings were shared by so many other participants). Several participants also made specific requests to clarify factual information, such as the label
used to describe their field of expertise. No participants said that their statements had been misinterpreted or otherwise asked for revisions.

**Findings**

In this section, I first present the findings that resulted from thematic analysis in response to each of four research questions. At the end of the section, I present additional emergent themes that do not directly address the research questions but are relevant in the broader context of this research. For each theme, I support the interpretation with sample quotes from the data.

**Research Question 1: What are some prevalent features of awe experiences in the context of science?**

**Participants’ Definitions of Awe**

In order to understand how participants were conceiving of the concept of awe, I asked them to define the term for me before asking for specific examples. This laid the groundwork for the examples that would follow and served to confirm that participants at least roughly shared a common understanding of the concept in question. In keeping with the epistemological approach to the study, I made the methodological decision to rely on participants’ own definitions because I felt this would yield richer data than providing a standard definition. None of the participants offered a definition that suggested a general sense of confusion about, or unfamiliarity with, the concept. However, many provided definitions – and later on, examples – that diverged from the standard conceptualization of awe in the literature. I viewed such divergences as findings because they suggested that some participants were associating awe in science with different types of experiences than those previously documented in empirical research.
It is important to bear in mind the context in which these definitions were collected and analyzed. First, while most existing research has identified themes through participants’ written or verbal accounts of specific awe experiences, the themes described below emerged from a direct request for a definition of the term early in the interview and represent participants’ top-of-mind understanding of the concept. As will be discussed in the following section, participants’ accounts of their own experiences with awe in this study revealed additional themes that did not always appear in their initial definitions. Moreover, while participants were asked for a general definition of awe rather than a definition contextualized in the domain of science, several participants did immediately provide domain-specific definitions. Overall, this is likely an artifact of the sampling process, as participants were aware that: a) the study focused on the emotion of awe and b) they had been recruited specifically because of their identification as scientists. However, as discussed below, these factors do not negate the finding that at least several participants view science and awe as inextricably linked. The subsequent section on features of awe-eliciting stimuli more directly addresses the nature of science-specific experiences of awe.

An analysis of participants’ definitions of awe revealed several themes that are consistent with the existing literature. The two key components of awe identified by Keltner and Haidt (2003) were both present: the *perception of vastness* (including vastness in space, time, number, and complexity) and the *need for accommodation* (i.e., being compelled to revise or replace one’s existing conception in light of new evidence). Additionally, two themes identified by Bonner and Friedman (2011) were prevalent: *presence* (i.e., full immersion in the current moment) and *ineffable wonder* (i.e.,
experiencing something inexplicable or mysterious). However, the relative prevalence of these themes diverged from prior research in several ways. Notably, over 80% of participants’ definitions included an element of *learning or realizing something new*, a broader category introduced in this analysis, which encompasses the concept of accommodation. In contrast, only one-fifth of definitions included a description of vastness or otherwise referenced a sense of scale. Figure 1 presents a graphical representation of the themes that emerged in participants’ definitions of awe.

![Figure 1. Percentage of participants whose definitions of awe included each of five prevalent emergent themes.](image)

**Learning or realizing something new.** As displayed in Figure 1, the majority (83%) of participants’ definitions of awe included an element of learning or being exposed to new information. Frequently, these definitions aligned with the previously established category of accommodation, or a shift in one’s perspective or understanding. Several participants described this sensation as an “a-ha” moment. As David described:

Awe to me is the feeling when you determine an undeniable truth. … It’s like, you learned these different things, they seem very unrelated, and then all of a
sudden, everything just fits together … and you have this kind of ‘a-ha’ awe moment. Maybe you’ve only been getting parts of it, but once everything really connects, you get this sense of awe.

Similarly, Ana explained:

It kind of changes your thinking, or paradigms, or it introduces you to something that you never really thought about. Often to the point of sort of stopping you in your tracks, or making you sort of pause in your thinking.

Often, definitions that fell into this category included a corresponding element of curiosity, or being motivated to seek further information. Nadia reported that awe “gives you feelings of curiosity. … Awe has a positive aspect to it that’s kind of, ‘that’s unusual but I want to know more about it.’” Will defined it as “a motivation to want to learn more. You know, sort of a thirst for furthering my understanding.”

**Sense of wonder.** Most definitions (73%) included an element of wonder or astonishment, often in the context of offering synonyms for the term awe, which was how many participants began their definitions. Definitions from 50% of participants included the words *wonder, amazing/amazement,* and/or *surprise/surprising.* These definitions frequently included a sense of profoundness or significance. Many also referenced intense visceral reactions to aesthetic experiences, such as feeling physically overwhelmed by something beautiful. Dawn defined awe as “being overcome by wonder, I guess. The feeling of just being amazed by something.” Andrew explained, “You feel this deep, deep impact, or reverence. You feel something incredibly profound, for a moment … something truly magnificent or beautiful, or something that truly shakes you.”

**Presence.** A number of definitions (60%) described something akin to what Bonner and Friedman (2011) categorized as *Presence,* or a sense of having one’s
attention fully captured. Such descriptions were often similar to a sense of being “in
flow.” Quinn stated:

In your mind, you have this constant narrative of what’s going on, and when you
experience awe, it just seems like that stops. And maybe instead of that cognizant
narrative always running, then maybe something subconscious kicks in, and all of
your senses are engaged, and you’re trying to really absorb what you’re seeing, or
hearing. Just, basically, you’re experiencing something unique, and in a way, it’s
sort of breathtaking.

Clara’s definition included a sense of being transported:

What makes an experience awe-inspiring is when it puts you out of your zone. So
much of our lives are spent in this bubble of today, tomorrow, the next day, ten
years from now, and then, you know, personal experiences in the past. But when
it feels so transcendent, like, this is the way it’s always been, but I never saw it
until now – that, to me, is awe-inspiring.

**Sense of scale.** One-fifth of participants’ definitions (20%) referenced a sense of
scale, typically in the context of experiencing something that is larger than the self. As
Ted posited, “It’s an emotion that you get when you feel really small, right? When you
feel like forces of nature are overwhelming. When you’re sort of…a fly in a hurricane, or
something.” Sarah explained, “It involves a size and power differential, meaning that to
me the experience of awe generally comes with the feeling that I am smaller or less
powerful than something else.” The relative infrequency of this element is notable given
its centrality in Keltner and Haidt’s (2003) definition.

**Relationship with science.** Finally, one-third (33%) of participants linked the
feeling of awe to the discipline of science in their initial definitions, prior to being
explicitly asked to discuss this relationship later in the interview. It is important to
consider, as previously noted, that the recruiting process likely primed all participants to
reflect on the connections between science and awe, and may have selected for
individuals who were especially likely to perceive such connections. However, it remains
worth mentioning that several participants defined awe as being integral to – or even solely evoked by – science. This perspective is perhaps best captured by the following exchange with Ian, an analytical chemist:

**Interviewer:** Do you think there’s something specific about that feeling of awe in the context of science that differs from awe in other domains? Or do you think the feeling is sort of the same, regardless of –

**Ian:** What do you mean by other domains?

**Interviewer:** Um, you know, being awed by nature...well, nature is sort of related to science...

**Ian:** It’s all science. Well, to me, science is a methodology, so when I hear the word science, science allows us to access all of these awe-inspiring experiences. So other domains, I mean...

**Interviewer:** I guess I’m thinking maybe by, you know, a beautiful piece of artwork or something like that.

**Ian:** I don’t know. I’ve never been, I mean, I appreciate people doing art, I took a lot of art, I can draw well and I play violin, and other stuff. But I wouldn’t be awed by...you know, I know some people that draw so well that it’s really amazing, but it’s not awe. It’s more like surprise. I’m not sure it qualifies as awe.

[later in the interview]

**Ian:** Science is a methodology. The word science, there’s words that we use that are, that the lay people use, and then we use them in a more precise way. So the word science for me is a methodology. But people, when they say science, they think of sciences [gestures broadly], all the things. But science in the pure sense is a methodology. It’s a way of finding truth. And so that’s what you apply, hopefully, and that’s what we all apply and try and discover how things work, right?

**Interviewer:** So for you, the things that cause awe for you are your observations of, or experiences with, the natural world or universe, and the methodology of science helps you to uncover those and understand them?

**Ian:** Right.
In total, four participants’ definitions (15%) included an assertion suggesting that their conceptual understandings of awe and science overlapped to some degree. However, the broader notion of science as a unique tool for unlocking knowledge about the universe surfaced later for many participants in the context of their examples of awe experiences; I will revisit this theme in relation to several of the other findings below.

**Features of Awe-Eliciting Stimuli in the Context of Science**

After providing a definition of awe, participants were asked to share multiple examples of times they had experienced awe in the context of science. Participants offered a rich, diverse set of experiences that included moments in their own work as professional scientists as well as earlier memories from their time as students. Once I had coded for the features of participants’ awe experiences, I used a mixed methods approach to investigate the extent to which participants fell into groups or clusters based on their patterns of responses. This analysis suggested that participants could not easily be grouped into clusters based on the features of awe that appeared in their examples. The results from this supplemental analysis are provide in Appendix C.

As will be elaborated below, the category of example provided by the most participants was the experience of developing a new conceptual understanding about science. Notably, very few of these discoveries came from the individuals themselves; participants repeatedly emphasized that the experience of making a paradigm-shifting discovery is incredibly rare and is not something they expect to occur in their own careers. Interestingly, despite these caveats, the scientific discovery process itself was also frequently cited as a critical source of awe. In fact, when initially asked to provide examples of awe experiences in science, most participants began with a story that focused
on the direct, authentic experience of scientific practice. It is also noteworthy that many examples included an element of scale, despite this not being a prevalent feature in participants’ definitions of awe. Figure 2 presents a graphical representation of the primary features that characterized the stimuli participants described as leading to their awe experiences in science.

*Figure 2.* Percentage of participants whose examples of awe included each of the six most prevalent features that emerged from the data.

In addition to examining all of the examples participants provided across the interviews, I pulled out the experiences participants described in their first responses to my request for an example. This enabled me to analyze just the features of the examples that were at the forefront of participants’ minds when they thought about experiences of awe in science. Figure 3 includes the same features in Figure 2 but displays the frequency of these features in participants’ initial responses. As Figure 3 shows, the process of discovery and sense of scale were the most common features of the awe-eliciting stimuli that participants described in their first examples.
Figure 3. Percentage of participants whose first examples of awe in science included each of the overall most prevalent themes.

Process of scientific discovery. Overall, nearly three-quarters (73%) of the participants described experiences of awe that involved their own practice of scientific inquiry; for half of the participants, this was a feature of the first example they described. Participants shared vivid memories of traveling to field sites, getting results in the laboratory, and observing scientific phenomena for themselves that they had previously only read about in textbooks. Embedded in these stories were several common themes.

Little victories. Many examples focused on the feeling of awe that accompanies a sense of accomplishment. In particular, those participants who conduct laboratory research frequently shared stories of designing an experiment that successfully yields results. Very few participants said that the awe came from a belief that their findings would be influential or paradigm shifting to the field at large; instead, they were typically stories of “little victories.” In fact, participants were often inclined to couch their examples in cautious language that differentiated between the process of conducting
research and any potential implications of the findings. As Francesca explained, “The awe, in terms of what I have done, [has] never been too much about the result. … I found the awe more in the challenge that I got, rather than in the final objective.” In one of Sarah’s examples, she distinguished between the impact that a discovery might have on the field versus the impact it has on her:

Another type of awe that I have experienced in my work is a type of awe that comes from making discoveries that no one has known about before. And for a very brief period of time, you are the only person who knows about them and who has ever known about them. You know, I’m not going to win a Nobel Prize for my grad school thesis, it’s not paradigm shattering or anything. But small interactions, or signaling pathways that my experiments sort of elucidated for the first time? To know that I know what’s happening and I’m the only person that does, to me there is a feeling of awe that goes with that.

A number of other participants echoed Sarah’s description of being the only person to know some small truth about the universe – a sensation that Eric, in his own telling, likened to stumbling upon a “secret garden.” Similarly, Luke explained:

There’s a weird moment when you’re doing science and you get a result, and there’s a moment right there where you’re the only human being in the entire world that has ever seen this and that understands how this one little tiny bit of the universe exists. And that is definitely a moment of pure awe, as long as you take a step back and you think about what you’ve just done. Like, you’ve just expanded human knowledge by one more iota.

**Exploring the world.** For participants who conduct research in the field, the sense of awe elicited by discovery was often closely tied to traveling to remote locations. Participants told stories of breathtaking landscapes, encounters with wildlife, and a unique sense of satisfaction that comes from surviving the physical and psychological toll of fieldwork. Dawn recounted the trip to conduct her doctoral research in northern Canada:

In order to get there, we flew in by sea plane and landed on the sea ice. I remember getting off the plane and just being completely surrounded by ice and
snow and mountains, everywhere you look. That was definitely a moment of awe for me. Just incredible beauty – and also, I guess, emptiness. I mean, it wasn’t empty of mountains and snow, but empty of signs of humanity. I found that quite incredible.

Likewise, Nadia described a compulsion to pull off the road to take in the sight of animals crossing the savannah at sunset during her first fieldwork trip to East Africa. She explained that her choice to pursue primatology was driven by a desire to “be an explorer” and “go places that no one else gets to go. I’m maybe one of a hundred-plus people in the world that gets to study wild chimps. That’s pretty amazing.”

**Seeing with one’s own eyes.** For both lab and field scientists, a common feature of discovery examples was firsthand experience. Nearly two-thirds of participants (63%) provided at least one example of directly witnessing something that they had previously only learned about through secondary sources like textbooks or lectures. Participants described a diverse array of scenarios that elicited awe when observed in-person, from a microscopic image of a mouse ovary to a mountain range in South America. As Clara explained,

For me in particular, those transcendental experiences have been not about what I’ve learned, but about how I’ve experienced something for myself that was there all along. Like the stripes on Jupiter, it was always there. People observed it in the 1700s with early telescopes, they could see it. I saw it too. That immediate connection between the history of something you’ve been told, and what you really experienced, was it for me.

**Conceptual understanding.** As might be expected given that so many definitions of awe included a component of learning something new, the vast majority (90%) of participants also described at least one awe moment that was elicited by a conceptual understanding of a scientific phenomenon, though these were typically not the first examples participants provided. For most of the examples in this category, the
phenomenon was within the participant’s own field of study but was not something the participant had personally discovered in the context of his or her own work. Rather, these were facts or concepts that the participants learned, primarily as students and sometimes later on in their careers through reading academic journals or attending conferences. Most participants focused on their early experiences of learning about large, fundamental concepts in their own fields. As Beth recalled:

The first time I had really studied the genome, I remember learning how complex and how perfect it was, and I just remember being floored by it. … I wanted to tell everybody about it, like, You guys don’t understand how crazy the genome is! You know, you think it’s just a sequence of four letters, randomly, over and over again. But there’s so many levels of it, and it’s just so perfect.

Similarly, Pearl described:

I remember when I was in college and I first studied relativity and quantum mechanics, it was a mixture of, I can’t believe I’ve now learned enough math that I can understand what my professor is talking about!, coupled with, Wow, I can’t believe I never knew this about the universe before! … Your mind is just sort of melting. Like, oh, that’s really what the universe is like? That’s kind of incredible.

Some participants also described being awed by more recent paradigm-shifting discoveries; for instance, three participants pointed to CRISPR/Cas9, a new technology that is able to change specific genes within living organisms. Additionally, several mentioned experiencing awe when learning about finer-grained concepts that were more specific to their own sub-field or specialization, acknowledging that these were likely not phenomena that would elicit awe in the general population or even in all scientists.

Though the majority of participants did not describe being awed by the implications of their own research findings, there were several who did; these experiences seemed to represent a blending of the discovery process and the conceptual understanding that resulted from that process. This mostly appeared in the descriptions of
participants closer to the end of their careers – especially Richard and Ian – who had achieved successes that were recognized as significant by the field. However, it was also the case for a handful of younger scholars. For instance, Yvonne explained a finding from her research group that she described as awe-inspiring and “transformative”:

In the lab, we do experiments where we get samples directly from patients and so we kind of run the same experiment but on different patients, and then see the results. And there’s a lot of things that are the same, that we all kind of respond to in the same way, but then there are a lot more that we respond to very differently, depending on our background and our genetics and all sorts of different factors that even we don’t know. So for me, that’s something that’s been really this transformative way of thinking, or this awe – how individual we each are. So when we’re trying to come up with kind of a one answer, or one-solution-fits-all, it really isn’t going to work because we are so different. … It’s understanding that when we look at people, they have all these different metabolic differences … all this stuff that they can’t even control that makes them react to things very differently. It has a lot of impact on how you view people in general.

**Sense of scale.** Though scale was not a component of most participants’ definitions of awe, it seemed implicit in their understanding of the emotion, as the majority of participants (80%) did reference scale when asked to provide an example of an awe experience. Most of these examples had to do with physical and/or temporal vastness. While several participants described vastness in the context of the landscapes they observed while conducting fieldwork, most referenced vastness in the context of contemplating the immensity of cosmological phenomena or the time scales of biological evolution. As Will observed:

> From the perspective of studying the earth, it’s not just size, it’s time. You start reflecting on the fact that you’re on this planet for just this hundred years or whatever, if you’re lucky. And trying to reconcile that with thinking about processes that are geologically recent that are a million years ago…it really provides a context that you don’t get from anything else.

At least six participants also mentioned feeling awed by brief or miniscule phenomena. For instance, James described the immense destruction that an earthquake
can cause in a matter of seconds – “not just in a geological instant, in a human instant.” Interestingly, Chris drew a connection between the sensation of awe that is elicited at both ends of the spectrum:

It still makes me feel small to look in a microscope and see single molecules. Maybe not small in scale, but insignificant, almost. It’s almost like looking at a starry sky, and when you start thinking about the distances involved, and the size of it can make you feel like you’re a speck in the universe, or something. But going the other way can do the same thing. Because it’s just like, these are a few tiny things that you read about in textbooks, but now you’re seeing them, and it makes you understand how many billions of those types of things have to combine into your body, for instance. So, I don’t know, I guess I think they’re sort of two sides of the same coin.

Membership in the scientific community. As displayed in Figure 2, the majority of participants (70%) expressed a sense of awe associated with their membership within an intellectual community spanning disciplines and generations. For many, the awe came from a realization that they were making a contribution to human knowledge, and a sense of being “in it together.” Francesca explained:

I felt when I published my papers, maybe some were more important than others, but this is my small contribution. It may not be the big awe, as Cas9 CRISPR, or [seeing] the earth for the first time, but it’s my contribution on the path that as human beings – with humility, with difficulties, with resilience – we keep following for a bigger goal. So the awe is not in what I have done, the awe is in the process.

Kyle, similarly, expressed a sense of science as a collective endeavor:

If you’re involved in this, you consider yourself part of a community, you know, a social community of human beings that are in this together to figure out how the universe works. You’re really rooting for people to figure things out. Even if they’re in competition with you! In general, you’re rooting for people to figure things out.

Several participants commented specifically on the feeling of being part of a long lineage of scientists. For instance, Vivien stated:

Science obviously has a long history. Everyone who came before you, down to
Euler, and Lagrange, and everyone who came before, hundreds of years ago … they saw the same thing, and they thought it was mesmerizing what they saw. And so you kind of feel yourself in this long legacy of scientists going back.

Some also described the ways in which this lineage extended forward in time through the contributions they saw themselves making as scholars and educators. As Ian explained:

At this point in my career, I’m just sort of feeling like I’ve sent out trained people that will continue the same process, as a teacher, I guess. Most humans like to transmit their knowledge; I think it’s inborn to most creatures and animals. So that’s what I’m looking for now. The idea is very satisfying that I’m spreading a way of knowing that I think is correct. Knowledge transmission.

Interaction between the capacity for awe experiences and expertise. Over half of the participants (53%) commented on ways that expertise interacts with the ability to experience awe. Many posited that sufficient content knowledge was necessary to recognize that a particular stimulus should be awe-eliciting. As David recalled:

One year I was in New York City, and they had an exhibit on Isaac Newton’s journals. I was looking at these old journals, I thought this was the coolest thing, and my parents were just like, Well, you know, whatever, they’re just these scribblings of math. And I was trying to explain to them that, no, you see, this very building that we are walking in wouldn’t exist without any of the equations, without the fundamental ideas behind physics, behind calculus. None of this stuff would have existed, you know? Like, we’d be in the Stone Age. So there is kind of an appreciation, like you have had to have gone through the experience of something in order to appreciate, to get that sense of awe when you learn something new, even if you didn’t necessarily work for it.

In the context of her own work, Eva explained that due to years of additional experience, she could retrospectively appreciate the value of her early research in a way she had not been able to in the moment:

I think [awe] totally changes, because you can conceptualize your work so much better as you get older, right? When you’re a young scientist, your focus is so narrow and on a very small piece of the world. But when you’re thinking about your own science and your own contributions and whether that’s cool or exciting or awe inspiring, being able to see how that fits into a much bigger puzzle takes experience. … I guess when I finished my dissertation I would’ve been like, well that was kind of disappointing. But now, when I can put that piece of information that I learned from my dissertation into the puzzle of the way that we do science
and approach it, now it’s actually really interesting. And so I can speak about my dissertation work in a way that has helped inform and move science forward, even though at the time when I finished, I didn’t see that.

Vivien expressed that this expertise differential presented a challenge in her teaching and mentorship:

Everyone experiences science very differently, and so what I appreciate about the different parts of the work that I do are, I think, quite different from what a lot of my students appreciate about what they do. I struggle to bridge that impasse of me being like, Oh my God, this thing, it is so small but so fascinating! And the kids are like, Why is that remotely interesting? But for me, part of that is I know the larger body of work done there, and I’m like, I haven’t seen this before in any conference I’ve been to. This is really bizarre, and we should poke that. And so that’s been a challenge for me to try to motivate the students in the same way that I feel motivated to study it. Because it’s quite abstract for them, and they’re not at the intellectual maturity place where they can find the same things fascinating.

While expertise seemed to enable a richer sense of awe in some contexts, participants also lamented that their capacity to feel awe was dissipating with increased experience. Several of the astrophysicists remarked that they had lost a sense of awe regarding the vast scales inherent in the work, a process Kyle referred to as growing “sanitized” to the numbers. Nadia shared that she no longer experiences the same sense of awe that she felt on her first trip to Africa, and acknowledged feeling jealous of those who still have their first visit ahead of them.

As the majority of participants in this study were still in the first half of their careers, it is hard to make definitive claims about how awe experiences change across the life span. The three oldest participants – Richard, Ian, and Owen – reported a diversity of perspectives regarding how their experiences of awe had developed over the course of their professional trajectories. For instance, Ian, reflecting on a career spanning nearly four decades, mused:

The problem is once you get awed to a certain level, I think it becomes harder and harder after that… I don’t know, maybe that happens to people as they get older,
they get less awed? ... Mars seems far away, but it doesn’t seem that far anymore. Enceladus seems far. The galaxies seem far, far away, and there’s a whole universe. That scale is awing right now. Mars isn’t as awing as it used to be.

On balance, Richard noted that a career’s worth of experience had not diminished his capacity for feeling a sense of awe at geologic time scales:

I mean, this thing [holding up a fossil on his desk] is roughly 380 million years old. That still blows my mind. And people say to me – my wife says, you know, “you can think of deep time. You know how to do it. You’ve been trained. You’ve had a lot of experience doing it. Me, it boggles the mind.” And I say to her, “Dear, it boggles my mind.” I don’t know what the hell 380 million years means in terms of human existence!

The complex interactions between awe, novelty, and expertise have pedagogical implications to which I will return later in this dissertation.

**Research Question 2: In what ways, if at all, do scientists see their awe experiences as transformative or otherwise impactful?**

While the methodological approach employed in this study does not enable definitive causal conclusions about the impact of awe, it did permit me to investigate how the participants perceived the impact of awe experiences in science. The interviews began with general questions about how participants would characterize the nature of that impact. Subsequently, I asked follow-up questions to inquire about topics of interest that had not already surfaced.

Both organically and in response to prompting, participants described a number of ways that awe experiences in science had impacted their perspectives and behaviors. Many of the described effects were related to themes of small self, positionality, and connectedness; I will return to these effects in the following section responding to Research Question 3. Here, I will present two other ways that scientists talked about the
impact of their awe experiences: impacts on motivation and impacts on epistemological perspective.

**Impacts on Motivation**

As I will discuss later in the section on unanticipated additional findings, several participants presented a bleak picture of science as a profession. Notably, however, many participants cited moments of awe as their motivation to keep going despite institutional pressures and challenges: nearly two-thirds (63%) said that experiences of awe contributed to their drive to continue pursuing science. As Ana put it, “Awe – or at least that sense of discovery, and kind of hoping for that awe – is sort of the only reason that you can survive in science.” Ben used the analogies of “food” and a “Pavlov’s dog”-like positive feedback mechanism to explain how small moments of awe kept him going through periods of hard work and rejection. Three participants used the word “fuel” to describe this sensation. For instance, Sarah explained:

> As much as I enjoy these experiences of awe, I would not describe most of them as particularly intense, I guess. They are more like low-key fuel, I would say. Like, this is why I do what I do, right? This is why I find my work worthwhile, because I think this stuff is cool, and I feel this sense of awe about it.

Several participants wondered whether something innate in their personalities might contribute to their desire to keep striving for this sort of feeling. As Isabelle mused:

> Being a scientist is kind of rough. [laughs] I like it a lot, but it takes this really kind of stubborn, weird mindset that I guess I have, I’ve figured out, but isn’t really normal or necessarily always productive. …Like, I’m just going to keep doing this thing until I figure it out. And I can’t tell you whether it’s the awe part that drives that – I think it is. Maybe I just intrinsically more than other people really want to know the answer so badly, and strive for that discovery feeling.

Earlier in this chapter, Luke was quoted as describing the unique discovery moments in science where “you’ve just expanded human knowledge by one more iota.” In the
continuation of that quote, Luke explained how he has guided other students to savor
these moments:

That’s the driver, I think, for a lot of what gets you through – what got me
through some really, dark, horrible, bad graduate school stories. Like, it can be
misery, and at three in the morning, when you finally get your program to run,
and you get the data, and it comes out, and you look at it, and you understand
what you’ve just done, you can’t let that go. Because you need those moments to
propel the rest of it. But those are definitely moments of awe. And I have passed
that on to other graduate students I’ve worked with. You know, they come into
the lab, and they’re like, Oh, you know, I got this result. And you just stop them
and you say: Before you tell me this, nobody else in the universe knows what
you’re about to say. Like, this is yours. This is your thing. And you don’t get a lot
of them, but when you get those, that’s kind of a big thing. And I don’t think we
should forget that. Because there’s so much drudgery, that if you don’t hang on to
those moments, I don’t know what else you hang on to.

**Impacts on Epistemological Perspective**

Beyond motivation, the other primary context in which participants talked about
the impact of awe was its contribution to a shifting perspective or worldview. One sense
in which participants experienced a change in perspective was in terms of their
understanding of science as a way of knowing. A number of participants recalled
experiences of realizing how various pieces of knowledge fit together as a coherent
whole. For instance, Quinn talked about the “big picture moment” when she first
understood the interaction between chemistry and physics. Ted, who is primarily a
theoretician, explained how an oceanographic cruise “altered [his] outlook on science” by
giving him a new appreciation for observational methods.

Additionally, nearly one-third (30%) of participants discussed ways in which their
scientific worldview interacted with religious beliefs (or lack thereof). For at least five of
the participants, science was seen as an alternative to religion; these participants
discussed how the awe that they felt from science served as a sense of spirituality or
purpose. Will explained:

One of the things that I think an understanding of science has done for me is given me a way to kind of understand the place of humans in the universe, both in space and time, in a way that maybe has filled a hole for me not growing up with any concept of God, or something like that. And it’s made it obvious to me that I don’t need that concept, either.

On the other hand, at least three participants felt that science informed their religious beliefs. Sarah, who had entered college as a Young Earth creationist, said that her biology training had caused her to re-envision her religious worldview. At this stage in her career, she said, “I think that the fact that I do believe in God feeds into my respect for and awe of the biological systems that I study.” Beth, who had not identified as particularly religious when she was growing up, explained, “I think learning how complex the genome is gave me more evidence that there has to be a God, because DNA is nuts. I feel like that kind of changed my perspective on everything, you know, on life.”

Research Question 3: In what ways, if at all, do scientists report on awe experiences that evoke a sense of “small self” and/or its associated prosocial implications?

As outlined above, this study was motivated in part by prior research connecting the emotion of awe to the sensation of “small self” and, in turn, a heightened inclination toward altruism or prosociality. Specifically, I wondered whether experiences of awe in the context of science might have an impact on participants’ sense of self in relation to the natural systems they study, perhaps even leading to an impact on their behavioral choices. Without prompting, some participants did describe impacts that aligned with the theme of small self. However, given its centrality to my research question, I also asked explicitly about this theme in interviews where it had not emerged in participants’ initial responses. The video clips from the film Overview, which introduced the idea of the
“overview effect,” also served as a form of prompting. After gathering participants’ initial reactions to the video, I asked whether they had experienced anything they would consider analogous to the overview effect – presumably on a less dramatic scale – in their own lives.

**Cognitive Impacts of Small Self**

At least once during the interview, most participants described a change in perspective that was related to a sense of scale, though this was typically not a component of their first examples. Participants tended to use abstract language that did not indicate how the participant as an individual, or humans in general, were positioned in relation to the vast phenomenon being described. Ultimately, over three-quarters (77%) of participants did discuss their positionality in relation to something larger at some point during the interview, but this often came as a result of further prompting. For instance, after Dawn described being awed by the vast geological time scales that she studies in her work, I asked if she ever found herself thinking about her own position in relation to these time scales. She responded:

> I guess in a lot of ways it is sort of positional, because the vastness doesn’t become apparent until you look at it relatively, to some extent. I often think about how humans … have been around for such a short period of time compared to the history of all life, and the world in general. The awe from that comes from looking at the relative time span. So I think part of it is thinking about my own small insignificant contribution to the vastness of the world.

In contrast, several participants commented that the vastness of the universe is simply beyond comprehension in the context of human scales. For instance, Henry explained:

> It turns out space is pretty empty. Very empty, actually. I think it’s hard to actually think of myself there on that scale. I could definitely see for other science, of course. . . . Earth is very easy, or at the biology level. But space, you
do kind of just separate yourself. You know, [in astronomic equations] you have this observer, and the symbol you use is a cross with a little curve, so it’s supposed to be like an eyeball. If you’re drawing some diagram, and you need an observer, that’s your symbol. And so you don’t even think about the fact that you are that [observer], you think about this kind of abstract eyeball looking on.

The *Overview* video clips also elicited responses about scale and positionality from participants who had not previously framed their own awe experiences in this way. Several participants remarked that their own work had provided them with analogous opportunities to “overview” a particular phenomenon. For instance, Urvesh suggested that working on problems in neuroscience offers an overview sensation in that it involves the act of using the human brain to study the human brain. As a microbiologist, Sarah concurred that, “there is something to be said about identifying biological processes that are happening within myself. … In some ways, I’m overviewing myself.” Ben, meanwhile, drew a connection to his own work as an ecologist studying vast temporal scales:

> These experiences with my science, thinking about these deeper time scales and understanding extinctions and the dynamics of earth – I worry a lot less about day-to-day life, and decade-to-decade life. …You know, when my children cry and they’re losing their mind over nothing, I can accept it and not get caught up in that. Or even fights with my spouse, I’m like, eh, this really is not that important. It’s important, but in other ways it’s just nothing compared to what I’ve seen, what I’ve experienced and seen other people live.

From a methodological perspective, there is always a concern that these kinds of direct prompts might be overly leading or may influence participants to share stories that are not actually significant in an attempt to appease the interviewer. To guard against this, I attempted to phrase questions in a way that did not suggest I was looking for a particular answer (e.g., “Some people have talked about experiencing awe in response to perceiving something vast in scale, though others have said this does not really contribute
to their feelings of awe. Does a sense of scale ever contribute to your awe experiences?”).

Several participants replied definitively in the negative to such prompts, suggesting that this strategy was at least somewhat effective. For instance, Luke responded:

I can certainly understand how that [sense of vastness] might be essential to some people’s definitions. I think what I would counter with…is that if we have a set of factors that contribute to awe, and then we have vastness, if you increase how vast something is, you can decrease all the other factors. But it doesn’t in and of itself, to me, convey awe. I think that when you see the depth of the complexity of something, I’ve definitely faced that void and just not cared, and it’s not interesting, and I don’t care how vast or complex or whatever, it just doesn’t do it.

**Behavioral Impacts of Small Self**

Participants were much less likely to link the feeling of small self to behavioral change. The handful who did described the impact as cumulative, rather than as the result of a single momentous experience. These participants explained that an understanding of their connection to the larger world influenced how they interact with the environment; such interactions were largely at the level of attention and appreciation rather than direct action. For instance, Owen, who was in the minority in saying that moments of awe in science impacted his personal life more than his scientific work, described how his relationship to the natural world had been shaped by these experiences:

It gets me out of my own skin. We live here in a city, we’re surrounded by a lot of people, a lot of buildings, a lot of built environment. If you see anything that’s not you at all, you see street trees…you swat some mosquitoes, depending on where you live, you dodge the rats or the mice. There’s just not much there. [But] there actually is a lot there, right? You don’t notice it. I notice it. And these kinds of experiences make me notice more, and make me more aware of the relationships between me, or people in general, and everything around us that isn’t people. … I think it sharpens my appreciation for non-human things and the diversity of non-human things makes me want to know more about that. But not necessarily, or not at all, really, in my day-to-day scientific work.

Several scientists did identify more active behavioral changes that they attributed to a sense of positionality or connectedness; these tended to be the participants who
studied environmental science or ecosystems. For instance, Ana posited that “ecology people” tend to make choices based on principles of conservation: “It definitely changes their behavior and the way they view the world … you go to these places, you realize what’s there and worth saving.” Mark explained that this sense of connectedness has translated to a desire to communicate with others outside his field:

I guess the impact of most of this stuff for me, it gives me more things to be enthusiastic about in terms of presenting the work and teaching other people. . . . I think in the sciences, we should be talking to people who aren’t professional scientists, because a lot of this stuff turns out to be very important for us to know in terms of making sensible decisions about how we as humans live in the world. . . . You know, where does our food come from? Where do we get our water? Where does our waste go? The world is big but it’s not that big. This stuff, it’s all connected.

**Additional Emergent Findings**

Several additional themes emerged in the data that, despite not providing direct responses to the research questions, shed further light on the nature of the participants and their emotional engagement with science as a discipline. Generally, these themes fell into three categories: 1) motivations for pursuing science, 2) perceived challenges with science as an institution, many of which were in tension with the ability to experience awe, and 3) perspectives about the pedagogical role of awe in science teaching and learning.

**Motivating factors for the pursuit of science.** Each interview began with a request for the participant to explain their current professional focus, and then to explain “how they got there.” Specifically, participants were asked to identify factors or experiences that they saw as influencing their career trajectory. The responses to this question are relevant to the broader motivations of this research, as they reveal common
themes in how a group of professional scientists found pathways into, and established personal connections with, the discipline.

Overall, participants’ stories incorporated elements of both “nurture” and “nature.” While they commonly cited early experiences with coursework and research and influences from family members as key factors, many also described possessing an innate sense of curiosity and other personality characteristics that motivated their pursuit of science. Additionally, the majority of participants’ stories of their career trajectories involved a degree of serendipity.

**Early academic experiences.** Every one of the 30 participants referenced encounters with coursework or teachers/mentors that influenced their trajectory into science (mostly in positive ways, though a handful of participants mentioned negative experiences that discouraged them from pursuing certain subject areas). Over half of the participants specifically noted the guidance of faculty mentors during their undergraduate or early graduate school experiences, and approximately half also discussed influential experiences in K-12 education that sparked their interest in science. Many participants also described early opportunities to get involved in scientific research during college or even high school, citing these experiences as some of their first introductions to authentic scientific inquiry.

**Family influences.** Influences from family were also crucial in shaping the career trajectories for many participants, including 63% who explicitly referenced the impact of family members. In childhood, this often came in the form of exposure to nature; participants recounted memories of stargazing, playing in the woods, and working on family farms. Others described family trips to museums and being taught to use the
household computer. Some participants whose parents or grandparents were professional scientists also described more explicit instruction and encouragement to explore the “family business.” For instance, Ana recalled reading science entries in the encyclopedia and viewing muscle cells under a microscope with her grandfathers, both of whom were physician researchers, and Vivien described her father as “a bit of a tiger dad” who encouraged her to intern at a research lab over the summer in high school.

In contrast, eight participants (27%) remarked that they did not grow up knowing scientists and/or were not fully aware of what it meant to pursue science professionally until they reached higher education. Gino remembered a college chemistry professor who said:

Well, from where we’re from, you only know doctors and lawyers. You know what I mean? If you’re smart, the professions that you’re told to aspire to are doctors and lawyers, and that’s it. You didn’t grow up knowing what a scientist does.

Similarly, Eric recalled:

[My parents] respected science, but that wasn’t their practice. … In high school, I never met a professional scientist, and that seemed like such a difficult, distant thing to even be. You know, you don’t meet anybody like that. You see them on TV.

Several participants who did not grow up around scientists mentioned that their parents still encouraged them to pursue science because they saw it as a practical or financially secure choice.

A number of participants also cited ways in which their family relationships have influenced their scholarly choices as college students and into adulthood. For instance, three participants explained that they were motivated to study neuroscience because they wanted to understand – and perhaps even positively impact – family members who faced
cognitive health challenges. From a more pragmatic perspective, several female participants commented on how pregnancies had impacted their ability to engage in fieldwork.

**Innate personality characteristics.** Another common sentiment (from 63% of participants) was the notion that the pursuit of science satisfies an intrinsic desire to understand the universe. This impulse was typically described as a character trait that had been present since childhood; as Will stated, “I was always kind of a ‘sciencey’ kid.” Beyond the family stories outlined in the prior section, participants shared numerous memories of more independent youthful pursuits, such as taking apart clocks to discover their inner workings and watching or reading science fiction. As Sarah described:

> I found it really interesting to finally have a way to get explanations for a lot of the natural world that I saw around me. I was always really interested in nature, I like being outside, and so to get this understanding that there’s this really cool science going on beneath the surface of what I could see all around me was really interesting to me.

Similarly, Luke explained, “I’ve always been curious. I’ve always been one of those people – I really want to know how things work, and I want to know why they work that way.” This echoes the previously described finding that many participants saw the experience of awe as closely tied to a scientific worldview.

**Serendipity.** Finally, 63% of participants explained at least some element of their career trajectory as having a serendipitous quality. Many described a process of “stumbling into” their area of expertise, often initially through involvement with their advisor’s research. James, who had majored in geology but worked at an accounting firm after college, eventually chose to pursue a Ph.D. after seeing a former professor who mentioned he was moving to a new institution and looking for students. Henry recalled
selecting “astrophysics” as his major when he applied to colleges because it was first on
the alphabetical list, never expecting he would enjoy his introductory coursework enough
to make it a career.

The fraught relationship between science and awe. Another important
emergent finding was the extent to which participants vocalized frustrations with the
challenges and constraints inherent in science as an institution. Perhaps it is not surprising
given the exceptional nature of the awe experience that participants’ stories of awe
regularly included an element of how hard-won those moments were. It is noteworthy,
however, how frequently participants positioned their moments of awe in tension with the
discipline of science itself. Participants lamented the demands to publish and the
importance of pleasing funders as limitations that prevented them from pursuing projects
that fulfilled their sense of curiosity and would have the potential to evoke awe. Quinn
described working on projects where the funding came with “strings attached,” and a
sense of being “indoctrinated” to think about the pragmatic benefits of research as
opposed to the elements that spark natural curiosity. Vivien observed that the pressure to
appease funders has increased as her career has progressed:

I think a lot of scientific pursuits do end up like that, you start to do something,
and then you see something shiny over there, and then you’re like, Whoa, that
thing’s really shiny, maybe I should go look at that instead! …But it does butt up
against a little bit of the, we have funding sponsors who have to see specific
things, right? When I was in grad school, and previous to grad school, I had a fair
amount of intellectual freedom to kind of putter around, and then if I saw
something shiny I would go for it. Now that I’m managing people and have actual
objective milestones, it’s a little more challenging.

Several participants also pointed to a sense of competition that dampens their
sense of awe – especially in the context of awe that they might have otherwise felt in
response to someone else’s success. Eric acknowledged feeling disappointed, rather than
excited, when he hears about a colleague’s discovery: “Things like jealousy, and career, and wanting to be successful and get promoted and all that sort of stuff, it really makes it hard to get that sense of awe.” Nadia noted that she appreciates traveling with colleagues to conduct fieldwork because “we’re all just sitting around having dinner, talking about chimps, and there’s no pressure, there’s no, let’s one-up each other, we’re not at a conference.”

Participants handled these challenges and constraints in a variety of ways. Many, as previously noted, turned to awe as a source of motivation in the face of professional obstacles. Some expressed that at this stage of their careers, they were more likely to find awe in teaching the next generation of scientists rather than in their own scientific research. Several left academia entirely, choosing instead to pursue industry and other more applied careers. Francesca, one of the scientists who had chosen to leave research and refocus her career on teaching, explained her reasons for leaving research in this way:

You know, it takes so much to discover what you discover, that at the end you’re so tired. You see your work, you see your sixty hours per week in the lab, you see your fights, you see yourself trying to be accepted at home for being different from everybody else, because it’s not normal to work sixty hours per week, and get out of bed at night to develop the last Western blot … There is no awe anymore, so this is one big reason. The second big reason is, again, there are a few privileged scientists who really develop these big ideas. I think that for the vast majority of the scientists, it is about surviving in something that has lost a lot of its meaning and has become just something as marketable as anything else. We’re fighting to publish so that we can survive and get grants. And it doesn’t matter what you publish, it doesn’t matter if it’s the story you wanted to package – because maybe there would be more awe if we package in a different way! … If reviewers don’t accept this conclusion, you don’t get the paper accepted. If the paper is not accepted, you’re not going to get the grant. At the end of the day, science is not anymore a place for awe. Research is a place of struggle. It is a place not even for wonderful ideas that everybody can believe. It’s a place for ideas that may stand in one lab, for that experiment, and who knows if even that
lab was able to replicate those data. This is the reality. I don’t see much awe in science anymore.

**The role of awe in science teaching and learning.** Finally, many participants offered their own perspectives regarding the value of awe as a pedagogical tool, based on their own learning experiences as well as their experiences teaching students. About half of the participants expressed that trying to instill awe was a goal they had for their own students. In keeping with their descriptions of their own awe experiences, many said they felt it was important for students to have firsthand experiences with authentic science. For instance, as Nadia lamented:

High school science is all about, like, here, take this textbook and memorize it, or do an experiment that’s been done before that you could probably look up on the internet, and not care about too much. It takes a long time till you get to the part where it’s like, let’s get to do something no one else has done before. Very few people ever get to that part, which is a shame. You know, I think everyone would say that you have to have kids doing science – but probably also not just doing experiments that have been done before, but actually like, maybe we should try something new. Maybe it’s okay if it fails. So many science experiments [in school] are designed for, we know this works. …There’s not an opportunity to cultivate that creativity, the really amazing creative part of science.

In addition to engaging in authentic inquiry, many participants recommended giving students the opportunity to observe scientific phenomena with their own eyes as an approach for eliciting awe. In particular, many named viewing wildlife up close as an effective strategy.

However, many participants also acknowledged that finding ways to evoke awe was an instructional challenge. One concern was about individual variation; participants found it hard to conceive of experiences that would be similarly evocative for all students. Others wondered about the threshold for achieving awe as opposed to less
strong or powerful emotions. For instance, Chris remarked on the challenges of moving beyond initial interest to a deeper sense of awe:

There’s a lot of things that would inspire interest, and even amazement, like, wow, that’s a cool science demo. Chemistry demos, I always think, are just weird, because they’re entertaining for the students, but they are not intended to convey any information. They’re just like, oh wow, chemistry is cool. But it’s no deeper than that, and that’s what you need for awe, or a revelation, you know, to connect something a lot deeper to the science, or to the demonstration. That’s hard to do.

Finally, several participants noted that it was difficult to plan for moments of awe because of their serendipitous nature. Pearl described the challenges of cultivating moments of awe for her high school students:

You can create lots of conditions, but you can’t make it happen. I try to do lots of things and lots of different hooks and lots of, you know, beautiful images or surprising things, but it’s maybe three kids that day, it’s going to be new to them and it’s going to be awe-inspiring, or maybe nobody. Every once in a while it’s the whole class and then you’re like, oh that was really awesome, but you can’t script it into your lesson. … We know a lot of the things that will really benefit our students, but it’s hard to figure out how to build the right conditions for it to organically happen.

Overall, participants expressed cautious optimism about the use of awe as a pedagogical tool, though with caveats about the feasibility of building it into instructional design. As Andrew summarized:

If you find what really matters to people, and you relate that to something, you can increase the chances. You’re stacking the deck, essentially, to generate awe in one individual. … In a classroom, certainly, that’s hard. But doable, I think. I think you can at least get to, like, transient moments of awe in a classroom.

**Discussion**

In this final section of the chapter, I begin by reiterating and synthesizing the major findings that resulted from the analysis. Subsequently, I discuss several limitations inherent in the study design. Finally, I conclude by proposing a set of implications and directions for future research.
Summary of Key Takeaways

Scientists’ definitions of awe overlapped with existing definitions in the literature, but with a particularly strong focus on learning and/or realization. When asked to define awe, participants’ responses aligned most closely with the need for accommodation component of Keltner and Haidt’s (2003) cognitive model, with the majority of participants saying that awe involved a need or desire to learn more about whatever it was they were experiencing. The other component of Keltner and Haidt’s definition, perception of vastness, was only reflected in one-quarter of participants’ definitions; however, their examples subsequently revealed that it, too, was a key element of awe experiences. Beyond these two elements, participants’ definitions focused more on how the emotion of awe feels rather than what elicits it; many participants defined the term by likening it to other emotions (e.g., wonder, amazement, surprise) and by describing the physical and mental reaction (e.g., being fully captivated, stopped in one’s tracks, etc.).

Scientists regularly experienced awe in response to both scientific content and scientific processes. Nearly all of the participants described feeling a sense of awe in response to science content, whether a foundational scientific principle they had learned about in school (e.g., relativity theory) or a more recent groundbreaking discovery (e.g., gene editing). However, for most participants, the question about their experiences of awe in science led first to a story about their own active participation in science, including advances in their research and memorable trips to field sites. Notably, these stories focused on the process of “doing science” rather than the outcome; participants were rarely awed by the implications of their own findings. Given the awe
that participants derived from the act of participating in science, it is perhaps unsurprising that many were also awed by reflecting on their membership within a vast lineage of scholars who have done, and will continue to do, this work.

**Scientists described impacts of awe experiences on their motivation, their perspectives, and to a lesser extent, their behavior.** I designed this study with the intent of exploring impacts of awe on how scientists viewed the broader world. Indeed, many participants reported that experiences of awe had contributed to shifts in their perspective or worldview; often, this shift was described as an increased sense of humility or reverence, or simply a greater appreciation for the vastness and complexity of the universe. Occasionally, participants described corresponding shifts in behavior, but rarely as a result of a singular awe-eliciting event. In short, and unsurprisingly, most scientists are not having experiences that resemble the intensity or drastic nature of the overview effect. Rather, their experiences of awe in science seem to contribute to their general outlook on life in ways that are more subtle and harder to define.

Finally, the most resounding unanticipated finding of this study was that the effects of awe experiences often have nothing to do with the larger world at all; on the contrary, the impact is often about one’s internal, personal journey as a scientist. Approximately two-thirds of participants described awe as a sense of motivation for their continued pursuit of the work. Frequently, this was framed as an antidote to the institutional pressures of science. As I will discuss further in the final section of this chapter, this finding has implications both for pedagogy and for the field of science more broadly.
Limitations

Before I conclude with the implications, several limitations of this study warrant acknowledgement: namely, it is important to consider how the findings may have been impacted by my recruiting strategy, by the nature of the interview protocol, and by my own interpretive lens as a researcher.

First, as mentioned previously, the study description used to recruit participants stated transparently that I was searching for scientists and that I wished to speak about their experiences of awe in the context of science. As a result, it is unlikely that this recruitment messaging would attract scientists whose work has never elicited a sense of awe. Correspondingly, while the participants reported differences in the frequency and intensity of their awe experiences, none of them said that they had no association between awe and science. Thus, it is important to be clear that the findings from this study do not suggest that all scientists experience awe in the context of their work. Rather, the purpose of the study was simply to illuminate the nature of such experiences as described by those who have them.

Second, as I have also discussed throughout this chapter, the interview protocol included prompts and follow-up questions to tease out the specifics of participants’ experiences. Asking direct questions about phenomena like scale, small self, and behavior change means that I cannot conclude with certainty which ideas were already in participants’ minds and which were suggested by the interview questions and video prompt. It is important to note that even though I had already told participants that the study was about awe, many of them took a lengthy pause before answering my questions about their definition of awe or examples of awe experiences, which suggests that these
topics were not at the forefront of participants’ minds prior to the study. In particular, it seems reasonable to conclude that few participants had been actively thinking about their sense of self in relation to larger systems, given that in many interviews, it took multiple prompts and follow-up questions to provoke a discussion of themes related to small self.

Finally, I must acknowledge my own biases as a researcher and the lenses I brought to the analysis, especially given my familiarity with the existing literature and my own prior experiences as a science learner and teacher. My use of a second coder served as one strategy to counteract this potential threat to validity, as it enabled me to determine whether the themes I identified in the data were apparent to an individual who was less familiar with the theoretical framing.

**Implications and Directions for Future Research**

The findings from this study contribute to our conceptual understanding of the nature of awe and its relationship with science and point to more concrete implications for how we educate and develop our current and future scientists. In this final section, I suggest several theoretical and practical conclusions that can be drawn from this work and propose ways that future research could extend our understanding in these dimensions.

**Implications for the literature.** This study presents evidence to support the hypothesis that has emerged in the existing literature regarding an underlying relationship between science and awe. In particular, the findings suggest that the accommodation aspect of awe as defined by Keltner and Haidt (2003) is especially relevant in scientific contexts; scientists in this study associated awe with surprising or intriguing phenomena that do not align with one’s existing mental model. Critically, as described by the
participants, awe leads not simply to the observation that one’s current explanatory framework has been disrupted, but a deep sense of curiosity and desire for further understanding.

The study suggests that more research is needed to explore the mechanism of small self in authentic contexts. In general, participants in this study did not connect their awe experiences, nor their feelings of smallness or connectedness, to corresponding prosocial inclinations or behaviors. On the contrary, the emphasis on motivation, as well as the “secret garden” notion of personal moments of discovery, suggests that many scientists saw their experiences of awe as having a primarily inward-facing impact. It is possible that awe triggers a different set of responses when elicited in the context of science outside the lab; alternatively, perhaps participants are in fact experiencing increased prosocial inclinations but at a level that is too subconscious for them to identify or articulate in retrospect. In future research, it would be valuable to conduct a “real-time” analysis of scientists at work, perhaps using some of the same instruments for measuring prosociality that have been utilized in laboratory research.

Implications for pedagogy. The extent to which participants’ awe experiences focused on the process of scientific discovery suggests that K-12 science instruction should involve more opportunities for authentic inquiry. Specifically, the idea of awe as “fuel” is a critical finding; many scientists report that they are “chasing” this feeling, which is a key motivator for their continued pursuit of the work. If our goal as educators is to help students experience a similar feeling as learners, it is clear that traditional “cookbook” lab activities will not suffice. While the need for authentic inquiry has been well documented in prior science education literature (e.g., Chinn & Malhotra, 2002;
Schwartz, Lederman, & Crawford, 2004), this study contributes the perspectives of professional scientists and highlights the motivational benefits that authentic inquiry may bring.

Additionally, it is clear that while many scientists have experienced the sensation of small self and are capable of reflecting on the implications of their work for their own actions in the world, these implications are not at the forefront of their minds when they think about their experiences of awe in science. For educators who wish to help students connect what they are learning to “real world” implications, especially regarding their own choices and behaviors, it is not safe to assume that these connections will happen automatically. Rather, the findings suggest that as learners develop a greater understanding of their position within complex natural systems, educators should provide sufficient scaffolding to help them identify opportunities to translate this new perspective to their daily lives. Future research should draw on well-established practices for supporting transfer (e.g., Perkins & Salomon, 1988) to design and test instructional moves that can support these instructional goals; such opportunities for transfer should be developed and investigated both while students are directly engaged in learning experiences that elicit awe and as they continue through their lives as science learners and citizens. For instance, instructors might build reflective writing exercises into instruction that has been designed to evoke awe such that learners can document the understanding they have developed as a result of this experience and record their ideas about how the new concepts connect to their lives. Another strategy might involve reminding students of their prior emotional responses – or perhaps even attempting to re-conjure those
emotions – to help them recognize the connections between the concept or experience that initially elicited awe and a new opportunity for transferring their understanding.

**Implications for the discipline.** Finally, while this study was not designed to address issues within science as a discipline, it is important to note that the findings suggest some disciplinary challenges that are hindering scientists’ emotional engagement and fulfillment, which in turn presumably affects the success of the field as a whole. Participants in this study described the institution of science as limiting their opportunities to experience awe, despite their statements that this emotion is a crucial source of motivation and encouragement. Notably, scientists’ decisions about what questions to pursue are driven by institutional expectations of productivity (especially publishing and acquiring funding) in a highly competitive field. Many participants reported that the innate sense of curiosity that motivated their initial decision to pursue science is being stifled by these external, more pragmatic factors, and some have even been driven out of the field. Future research is warranted to investigate the impact of these institutional constraints on the motivation and well-being of individual scholars, as well as the productivity and sustainability of the field writ large.

In the concluding section of this dissertation, I will return to this study to draw broader implications for theory and practice. In the following chapter, I present the second of two studies conducted for this dissertation, which focuses on the experiences of adolescent science learners.
Chapter 4 | Study 2: Adolescent Science Learners’ Understandings of Connectedness

Introduction

Several key findings emerged from the investigation of scientists’ awe experiences in Study 1 that may have implications for designing meaningful instructional experiences for science learners. First, scientists describe their experiences of awe – especially during moments of discovery – as a strong, and perhaps even necessary, motivator for continued pursuit of science. This finding provides further support for claims in the existing literature that designing science instruction that is meant to elicit awe in the learners is a worthwhile endeavor, though these prior arguments (e.g., Valdesolo, Shtulman, & Baron, 2017) tend to focus on the role of awe as a tool for facilitating conceptual understanding rather than motivation.

Second, scientists’ experiences of awe could generally be sorted into two primary categories: those experiences elicited by active engagement in scientific research, and those elicited by scientific conceptual knowledge. Moreover, while some recurrent themes emerged, there was variation in the features that elicited awe from one participant to the next, suggesting that it is not safe to assume that there are many universal “triggers” of awe in science. Thus, providing opportunities to engage in authentic scientific practice and introducing students to a variety of eye-opening scientific concepts both seem to hold instructional promise, but educators should not expect that all learners will react similarly to instructional activities that are intended to elicit awe, nor is there a guarantee that educators will always be able to correctly identify whether they have elicited awe in their learners.
Finally, when asked to describe the impact of their awe experiences, scientists often described the effects as confined to the initial context of the discipline (such as the aforementioned motivational impact). Additional follow-up questions and the video prompt did yield more examples of how scientific awe experiences led to broader shifts in perspective, and a number of participants offered descriptions that resonated with the sensation of “small self” described in the existing literature (Piff et al., 2015). However, even with this probing, very few scientists said that experiences of awe in science impacted their behavior. This finding indicates potential challenges for educators who hope that their learners will transfer their experiences of awe in science beyond the initial learning context. It also raises questions about whether the documented effects of small self in laboratory settings carry forward into more complex real-life contexts, and whether intentionally designed cues for transfer might help individuals recognize opportunities to make connections between experiences of awe in science and their lives outside the laboratory, field site, or classroom.

In Study 1, I focused on the awe experiences of professional scientists in order to learn from individuals with significant expertise in the discipline who had made a relatively long-term commitment to science. However, the majority of students do not go on to pursue careers in scientific fields. Therefore, in Study 2, I turned my attention to the experiences of adolescent science students, who will grow up to be consumers, but not necessarily practitioners, of science. Given that nearly all of the existing research on awe has been conducted with adults, I chose to focus on adolescents in this study as a first step in building a bridge from adults to younger learners. A key focus of this study is the extent and nature of students’ reported tendencies to make connections to their lives
beyond the initial learning context. In particular, I use the framework of transformative engagement, which I will discuss in the subsequent section, to investigate more specifically the types of contexts in which students are able and inclined to apply their new understandings (for instance, to science knowledge they have acquired elsewhere, to their career and other future endeavors, to their sense of self, etc.).

**Conceptual Framework**

As of 2016, scientists and engineers accounted for less than 5% of total employment in the United States (Sargent, 2014). Most students in science classes at the K-12 level, and even many enrolled in college-level science courses, will not go on to become professional scientists. As science educators, it stands to reason that our goals must extend beyond career development.

Science educators and researchers seem to broadly agree that science literacy, defined expansively, is a desirable goal for all students (e.g., Snow & Dibner, 2016). One reasonable purpose for science literacy exists at the individual level; an understanding of science can help students develop a personal appreciation for the universe and their place within it. As the landmark report *Science for All Americans* (American Association for the Advancement of Science, 1989) declares, “Humans have never lost interest in trying to find out how the universe is put together, how it works, and where they fit in the cosmic scheme of things. … All humans should participate in the pleasure of coming to know their universe better” (p. 39). Yet the goals for science literacy extend beyond personal fulfillment. *Science for All Americans* argues that the broader, and perhaps most pressing, aim of science education is to empower young people “to participate thoughtfully with fellow citizens in building and protecting a society that is open, decent,
and vital” (p. xiii). As more recent attempts at defining the scope of scientific literacy have suggested, preparing students for meaningful science-related civic participation involves helping them understand the sociocultural context in which science is embedded (Rudolph & Horibe, 2016), as well as the principles of causality and systems thinking that are necessary to make sense of the complex interactions between humans and our environment (NGSS Lead States, 2013).

The present study focuses on the interaction between these inward- and outward-facing goals through an investigation of science instruction designed to facilitate students’ understanding of their relationship to, and role within, broader natural and societal systems. Moreover, I explore whether the emotion of awe serves to prompt this sort of outward-facing orientation. As outlined earlier in this dissertation, experimental research on small self indicates that awe serves as a trigger for increasing prosocial inclinations “by broadening the individual’s perspective to include entities vaster and more powerful than oneself and diminishing the salience of the individual self” (Piff et al., 2015, pp. 895-896). In the context of environmental science education, for example, an orientation toward the collective might involve a deeper understanding of one’s impact on the local environment, and a corresponding prosocial behavior might entail choosing not to dump waste in the nearby creek because of its effect on the organisms who inhabit it and the individuals who live downstream. As another example, an orientation toward the collective in the context of a unit on natural selection might involve a heightened awareness of how all humans are derived from a common ancestor; a resulting prosocial behavior might be to recognize the similarities between individuals and treat those who appear outwardly different with greater respect.
Outside of the laboratory, however, the link between awe experiences and increased prosociality may be more tenuous. The findings from Study 1 suggest that while some awe experiences did seem to encourage participants to reflect on their position in relation to larger phenomena and systems, these reflections were not at the forefront of most participants’ minds and rarely led to behavioral changes. Thus, while undergoing an awe experience in science may facilitate a perspective shift, learners may have trouble identifying opportunities to apply this new perspective to their lives in tangible ways unless they are provided with explicit cues for transfer.

To more systematically examine the ways in which students apply what they have learned to their own lives, I draw on the theoretical framework of transformative engagement. Pugh (2002; 2011) has proposed the construct of transformative engagement to capture the complexity of situations that lead to transformative learning. Specifically, Pugh (2011) defines a transformative experience as “a learning episode in which a student acts on the subject matter by using it in everyday experience to more fully perceive some aspect of the world and finds meaning in doing so” (p. 111). Notably, “a transformative experience does not have to be a global, life-changing event” (Pugh et al., 2017, p. 101); rather, transformative experiences in a classroom context are more likely to be common, everyday events that trigger a sense of connection or meaning for a student, thereby making transformative engagement a feasible goal for educators.

In the transformative engagement framework, transformative experiences are defined by three interrelated characteristics:

1) motivated use (i.e., choosing to apply the content in new contexts),
2) *expansion of perception* (i.e., seeing some aspect of the world anew through the lens of the content), and

3) *experiential value* (i.e., feeling that having learned the content was worthwhile).

These three components are meant to roughly correspond to the behavioral, cognitive, and affective aspects of engagement, respectively. Notably, in this framework, the affective characteristic of experiential value encompasses two distinct types of value: intrinsic value (i.e., interest or fulfillment) and utility value (i.e., a sense that the content will be useful for one’s future life experiences or goals). Pugh and colleagues argue that an experience cannot be characterized by this component unless both conditions are met; in other words, a learning experience that a student recognizes as pragmatically useful but does not find enjoyable or fulfilling (e.g., studying for the SATs, perhaps) would not qualify, nor would an experience that is enjoyable but is not seen has having further application beyond the immediate context. However, as I will subsequently describe, the features of the learning environments that are the focus of the present study are quite likely to trigger one of these responses without the other. Thus, in the analysis that follows, I pull out each of these components individually in addition to examining the characteristic of experiential value as a whole.

Pugh et al. (2017) have suggested that further study of student learning using microgenetic analysis or longitudinal case study approaches would shed light on the developmental processes of transformative experiences. In this study, I apply the framework of transformative engagement to the experiences of learners who are participating in science courses that have been designed with a goal towards helping
students understand the relationship between themselves and the broader scientific concepts that are addressed in the course. To do so, I analyzed instances of students’ transformative engagement as they occurred throughout the course as a whole, in addition to specifically examining instances of transformative engagement in the context of students’ ideas about their connections to larger scientific systems and phenomena.

**Research Questions**

This study builds on existing research on awe, small self, and the orientation toward the collective. It has been designed to advance understanding of these phenomena in three contexts: in authentic learning settings outside the laboratory, in the disciplinary context of science, and as experienced by individuals on the cusp of adulthood. The study was guided by the following overarching research question and sub-questions:

1) How do adolescent science students engage with an instructional experience that is intended to facilitate their understanding of the individual as connected to something larger than the self?

2) In what ways, if at all, does their engagement appear to be transformative?

3) Is there evidence that the emotion of awe plays a role in this learning process, and if so, how are these feelings evoked through the instruction and experienced by the learners?

**Methods**

The methodological design of this study was based in microgenetic analysis, an approach used to capture the details of a specific cognitive developmental change through repeated observation of individual participants (typically children) over a relatively short period of time (Siegler & Crowley, 1991). Microgenetic studies are defined by three key
principles: 1) observations span the entire duration of the phenomenon, 2) the density of observations is high relative to the rate of change of the phenomenon, and 3) behavior is analyzed repeatedly in order to infer the causes of the change (Siegler & Crowley, 1991, p. 606). This design aims not to control for specific variables but rather to explore what emerges in students’ thinking when they have access to a set of instructional experiences and supports. Pugh et al. (2017) explicitly recommend microgenetic studies as an ideal approach to “help unpack the nature of transformative engagement as it first emerges and develops to become more representative of a genuine transformative experience” (p. 25).

Site Selection

Studying a phenomenon across multiple settings serves to “strengthen the precision, the validity, and the stability of the findings” (Miles & Huberman, 1994, p. 29). For this investigation, I selected two sites which served as reference populations. The concept of reference populations is borrowed from ecosystems science and is used as an approach for studying contrasting features of different contexts in scenarios where the notion of a control group is not applicable (Grotzer et al., 2015). Intentionally selecting instructional contexts with apparent differences in their surface features (e.g., the content area or the pedagogical approaches) also served to illuminate any deep structural similarities between the settings (Goldstone & Sakamoto, 2003). In each setting, my inquiry was focused on how the students’ learning appeared to interact with the site-specific features of the instructional context.

Situating this study in summer programs enabled me to observe a course of instruction from start to finish, with students who were coming from a range of backgrounds and schools to engage in this shared learning experience. To recruit
potential sites, I identified programs or courses that: a) explicitly referenced the concept of connectedness in science as an understanding goal and b) had a target audience of adolescent learners. Ultimately, I selected two six-week summer school programs, each of which was hosted at a higher education institution: Darby University and Gifford University. Darby and Gifford are both elite institutions located in the same metropolitan area of the Northeastern United States. Each university offers summer programming for undergraduates and for high school students who wish to take college-level coursework and experience other aspects of college life. At each university, I selected one summer science course to observe based on the publicly available descriptions of the course content and goals. The two programs spanned the same six weeks during the summer of 2018.

**Darby Summer Institute: Junior Science.** My investigation at Darby University was situated within the Darby Summer Institute (DSI), a multi-year program for local low-income high school students who must be nominated by a teacher in order to apply. DSI admits students in the summer after their freshman year of high school and hosts a sequence of programming for three consecutive summers. Enrolled students live on campus during the week and go home to their families on the weekends. In addition to covering tuition, room, and board, DSI gives each student a tablet and a summer stipend and awards a modest college fellowship to students who successfully complete all three summers of the program. DSI students take a series of required courses in STEM and the humanities, attend regular workshops for college preparation and career development, and participate in social activities.

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5 Pseudonyms are used for the names of the institutions, programs, and participants in this study.
I selected DSI because the program advertises that their STEM curriculum is designed to focus on issues of “identity and community.” The program description also noted that students would produce work portfolios that could be shared with their communities. This emphasis on the connection between scientific understanding and direct impact on students’ local neighborhoods and networks suggested that DSI’s goals were in line with the instructional features I sought to study. Specifically, I chose to observe the science course for rising juniors (i.e., students in their second summer of DSI), which is focused primarily on genetics and is intended to preview some of the material in Advanced Placement Biology. I selected Junior Science as opposed to Sophomore Science because the students would be closer in age to the students at my other site, Gifford University. (DSI does not offer a Senior Science option because students enroll in electives in their third summer.)

DSI Junior Science met in 75-minute sessions four times per week over six weeks. The instructor for the class I observed was Lily (who asked students to call her by her first name), a veteran science teacher who has taught at DSI for many summers and has been heavily involved in developing the program’s STEM curriculum. The class also had several undergraduate and graduate student assistants whose responsibilities included setting up labs and grading assignments. Fifteen students were enrolled in Lily’s class (the other half of the junior cohort took the same class with Julio, another long-time instructor at DSI). Students participated in weekly labs, had regular homework assignments and two exams, and were expected to submit “double-entry journals” (referred to as “DEJs”) where they took notes on the assigned readings in one column and recorded their reactions to and questions about the text in the other.
**Gifford Summer Session: Chem 106.** My investigation at Gifford University was situated in a stand-alone course offered through the Gifford Summer Session. Gifford Summer Session courses are open to undergraduates at Gifford and elsewhere who are looking to fulfill credits over the summer, as well as to rising juniors and seniors in high school, who must apply for eligibility by submitting a transcript and a letter of recommendation. Gifford offers a comprehensive residential summer program for high schoolers that includes college prep workshops and social activities, but local students can also choose to simply enroll in one or two summer courses and commute from home. Gifford Summer Session students are responsible for tuition, room and board, and other fees (costing over $10,000 for residential students), though a limited number of need-based partial scholarships are available.

The course I observed at Gifford is colloquially known as “Chem 106” but is in fact an interdisciplinary course that is co-offered by multiple science departments. Chem 106 had been previously taught by a team of science faculty as a semester-long course, but restructuring it for a six-week session with one instructor was a new experiment in the summer of 2018. I selected Chem 106 because of its emphasis on the “big picture” – the course is framed as an exploration of cosmic evolution, beginning with the Big Bang and progressing through the origins of the galaxies, our solar system, life on Earth, and human consciousness and culture. As described in an early version of the syllabus, “Technically, the course requires no preliminary college science and does not prepare you for any advanced college course. But it may change your life.”

Chem 106 met in two-hour sessions three times per week over six weeks. The course was redesigned and taught by Professor Holden, a long-time member of the
Gifford chemistry department who had been involved in earlier iterations of Chem 106 but never as the primary instructor. The Teaching Assistant, Kiyana (a recent graduate of Gifford with a Ph.D. in chemistry) was responsible for grading and a variety of other logistical tasks. While the original roster showed 17 students, around a dozen showed up for the first few days, and the enrollment eventually settled at 9. (Professor Holden suspected that the low enrollment was due, at least in part, to an error in the course catalog that had originally advertised the class as meeting at a different timeslot.) The class was primarily lecture-based and did not include labs. Students had assigned readings, regular homework assignments and quizzes, and were expected to keep a weekly journal where they tracked their personal reactions to the course content.

**Participant Recruitment**

Prior to the start of the summer, I gained program-level and instructor-level permissions to conduct research at each site, but recruiting individual student participants could not be done until the programs began. On the first day of class at each site, I introduced myself to the students, explained my purpose as a researcher and the nature of my study, and clarified how my role in the classroom would differ from those of the instructors. I invited students to ask questions about the study and passed out consent forms to all students so that they could read the description on their own and decide whether they wanted to participate. Interested students returned their signed consent forms to me in a subsequent class session. For students under 18, I distributed consent forms to their parents or guardians and obtained signatures from both the adult and the student. Students could choose to sign up for any or all of the three modes of data collection involved in the study (interviews, observations, and sharing written work). At
Darby, a total of eight students (out of 15) enrolled in the study; three students consented to participate in all three modes of data collection, and an additional five students consented to participate only in observations and sharing written work. At Gifford, a total of four students (out of 9) enrolled in the study, and each of the four consented to participate in all three modes of data collection. Table 2 displays the types of data collected for each student at each site.

Table 2

<table>
<thead>
<tr>
<th>Types of Data Collected from Each Student Participant</th>
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<tbody>
<tr>
<td>Student Pseudonym</td>
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<tr>
<td><strong>Darby (DSI)</strong></td>
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<tr>
<td>Karim</td>
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<tr>
<td>Fatima</td>
</tr>
<tr>
<td>Maria</td>
</tr>
<tr>
<td>Yara</td>
</tr>
<tr>
<td><strong>Junior Science Students</strong></td>
</tr>
<tr>
<td>Victor</td>
</tr>
<tr>
<td>Edward</td>
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<tr>
<td>Gabby</td>
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<tr>
<td>Alisha</td>
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<tr>
<td><strong>Gifford Chem 106 Students</strong></td>
</tr>
<tr>
<td>Sophie</td>
</tr>
<tr>
<td>Dylan</td>
</tr>
<tr>
<td>Nicholas</td>
</tr>
<tr>
<td>Olivia$^6$</td>
</tr>
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</table>

Based on my limited observations of students who did not opt to participate in the study (e.g., from their in-class contributions), I believe that my participants are generally

$^6$ I informed all students at the start of the summer that signing up to participate in interviews would entail two sessions: an initial interview and a concluding interview. When I approached the students to schedule our concluding interviews, Olivia was hesitant to make plans, saying that she was busy with her summer job and was not sure she had time to meet for another half hour. She also asked for more information about my purpose in conducting a second interview. I explained that I was interested in learning about how her thinking had changed over the course of the summer, and she told me that she did not feel her thinking had changed. Ultimately, Olivia was not ready to commit by the last day of class and did not respond to my follow-up message inquiring about her participation. It is impossible to know Olivia’s full reasoning for declining to participate: she may genuinely have believed that her thinking had not changed, may not have had the chance to reflect on her thinking and felt unprepared to discuss it, or simply may not have wanted to take the time for an additional interview.
representative of the range of engagement at each site, in terms of both the frequency of their contributions and the nature of their thinking. Due to the nature of the research questions, my quotations from participants and excerpts from field notes primarily represent the range of engagement to the extent that it was present. However, as appropriate, I have also attempted to present examples of absence of engagement, including instances where students were seemingly confused or unmoved by the content.

Procedure

As described above, I collected data in the form of classroom observations, one-on-one interviews, and written work such as reading journals and problem sets. The classroom data provided information about the features of instruction and observable student engagement with that instruction in real-time (including dialogue and visible reactions such as facial expressions). Interviews and document analysis provided further information about how students were experiencing and responding to the instruction. In addition to student interviews, I conducted one interview with each instructor after the programs had concluded. These reflective interviews enabled me to further investigate how Lily and Professor Holden reasoned about their pedagogical approaches and interpreted their students’ responses, as well as the extent to which they felt their implementation of the instruction had aligned with their curricular goals.

Observations. To investigate the features of the instructional moves and corresponding student reactions, I attended class every day during the duration of each program, resulting in 34 hours of observations in Chem 106 at Gifford and 26 hours of observations in Junior Science at Darby Summer Institute (DSI). During my visits, I attended closely to verbal and non-verbal cues regarding students’ emotional states
during instruction and made note of specific instructional approaches or moments that I wished to reference during follow-up interviews. I took field notes during each visit and expanded on them soon after to record additional descriptive notes as well as interpretive notes that captured my methodological reflections and emerging hypotheses about the data (Creswell, 1998). A protocol with the prompts I used to guide my field notes is available in Appendix D. Specific notes about student behavior were confined to those students who had consented to participate in observations.

**Interviews.** I conducted one-on-one semi-structured interviews lasting approximately 20-30 minutes each with consenting students at each site to document their thinking over the duration of the summer program. For Chem 106 students, the first round of interviews was conducted in the first week of the course; at DSI, the interviews were conducted during week two due to programmatic scheduling constraints in the first week. I conducted a second round of interviews with the same set of students during the final week of the course at each site (aside from one student in Chem 106 who opted out of the second interview). I developed semi-structured protocols before beginning data collection but added further questions in response to what I had observed from classroom visits and written work. A sample interview protocol is available in Appendix E. I also conducted briefer, spontaneous questioning (e.g., “Can you tell me about how you’re interpreting these lab results?”) with participating students during activities where it was appropriate for me to engage them in conversation. As noted above, semi-structured interviews with the primary instructors at each site were also conducted following the completion of the programs in order to understand their thinking behind the instructional design and implementation.
**Document analysis.** To further my understanding of the participants’ thinking, I collected a variety of course documents, including samples of student work (e.g., journals, homework assignments, quizzes, and projects) as well as instructional materials (e.g., syllabi, assigned readings, and lesson plans). Written work captured student thinking about a broader range of topics than I could address in the interviews; moreover, it served as another form of expression for students who were less comfortable sharing their thinking in verbal conversation.

**Analytic Plan**

To analyze these multiple data sources, I relied on a blended strategy that Timmermans and Tavory (2012) have labeled “abductive analysis” and Deterding and Waters (2018) have more recently described as “flexible coding.” Like grounded theory (Charmaz, 2006), abductive analysis involves emergent coding, but unlike grounded theory, it puts the findings – particularly anomalous or surprising findings – in conversation with existing theory from the outset of analysis (Timmermans & Tavory, 2012).

In the first phase of analysis, I organized the data chronologically by participant, compiling all of the observational notes, interview excerpts and written work for a given student into one document in the order in which it was produced. From these documents, I developed an analytic memo for each participant, noting emerging themes that I had identified both within and across participants. During this initial stage, I recruited two additional coders who were well versed in qualitative analysis to independently conduct thematic analysis on two focal students per site. Following their individual analyses, we had several conversations to discuss the themes we had each identified within and across
participants. I used these conversations and the notes from our individual analyses to begin developing a list of codes, which I supplemented with additional codes based on existing theory (e.g., the components of transformative engagement, previously documented features of awe experiences, etc.). I then conducted a second phase of analysis in which I applied this codebook to the full dataset. During this coding process, multiple codes could be applied to the same “codable moment” (Boyatzis, 1998). The findings reported below are the end product of these multiple, iterative phases of analysis.

To analyze the nature of students’ transformative engagement, I looked for evidence of at least one of the components of transformative engagement as defined by Pugh (2002), rather than only coding moments where all three components were present. A codebook with definitions and examples of these individual components is provided in Appendix F. It is important to note that, given the structure of this study, I did not see the students outside of the primary learning context (aside from meeting for interviews). Therefore, I was not able to observe instances of the students choosing to apply the content in other settings. Instead, I looked for evidence of transformative engagement in other contexts where students had opportunities to express the connections they were making to their lives outside of the course, such as through the notes in their journals, the comments they made in class, and the examples they provided in interviews. Therefore, some of these instances might involve more explicit prompting for application or connection-making than the “spontaneous” applications envisioned in Pugh’s framework. By Pugh’s definition, for instance, “[u]sing the concept of evolution to answer a test question on evolution or complete a school assignment on evolution is not motivated use” (Pugh, 2011, p. 112). However, for the purposes of this study, I was interested in how
students chose to apply their knowledge and the nature of the connections they identified, even if they were generally encouraged to make these connections by a journal prompt or interview question.

Per the discussion in the conceptual framework section above regarding experiential value and my expectation that the class activities might be likely to elicit intrinsic meaning or pragmatic utility but not necessarily both, I coded as experiential value any instance that showed evidence of either of these two sub-components. Subsequently, I broke down these codes to determine how many instances of experiential value included both of these sub-components as opposed to only one.

Finally, it is important to note that while this study was designed using the principles of microgenetic study, I discovered during the process of familiarizing myself with the data that mapping paths of change for individual students was not an appropriate or especially useful strategy for analysis. Notably, the nature of the thinking that students demonstrated in their initial interviews, which occurred only several days into instruction, was generally quite similar to the thinking demonstrated in the concluding interviews during the last week. Thus, rather than revealing narratives of change over time, the data presented a relatively stable picture of the patterns of thinking that were invited and inhibited by two distinct learning environments with unique instructional features. As a result, I have structured the findings thematically rather than as chronological accounts.

**Findings**

In this section, I present the study findings first in the context of Junior Science at Darby Summer Institute and then in the context of Chem 106 at Gifford University. For each site, I begin by offering some additional context about the nature of the instruction I
observed, particularly in terms of how it related to the stated goals for the program or course, before presenting the findings that resulted from thematic analysis in response to each of the research questions. I conclude the section with reflections on notable similarities and differences within and between the two sites.

**Darby Summer Institute: Junior Science**

*Instruction at DSI Junior Science was heavily structured, with a focus on supporting students in skill development and content mastery.* Junior Science at DSI met in 75-minute sessions four times per week. In general, the course was structured such that Lily presented a lecture on Monday that would set up the lab work conducted by students on Tuesdays and Thursdays, while Fridays were reserved for reviewing content. Lily explained that she had redesigned the curriculum after DSI alumni reported that they were unprepared for processing complicated texts and taking effective notes in their college science courses; as such, the current iteration of the course places more emphasis on developing these skills. Similarly, the lab component of the program is designed to give DSI students comparable experiences to their peers in other districts. Lily explained that they selected the topic of genetics “because it lent itself to doing things like pipetting, PCR, and gel electrophoresis, which we knew most schools they were coming from couldn’t afford.”

As previously described, DSI’s online summary of their science sequence describes the program as focused on the overarching themes of identity and community. I asked Lily about the extent to which the current DSI curriculum aligns with this description, and she acknowledged that the program has drifted from these themes since its inception nearly 15 years ago, though they are now trying to refocus on some of these
objectives. In particular, the instructors are still committed to exploring several of the essential questions listed on the website, including “How can I make a difference in the lives of the people around me by studying science?” Lily explained,

We are trying to do more of this, but we really try to make connections between what we are learning and new technologies that are changing the face of genetics. And we talk about the effect that discoveries in the past have on life today. I’d like to do more bioethics if possible, especially with the dawn of CRISPR and new reproductive technologies. Some people think that we are on the brink of a new eugenics movement, and that is really frightening. If they are to go into science, which many of the scholars want to, they are going to need to know the ethical issues they will be facing.

Perhaps unsurprisingly given this ambitious mix of learning goals, a striking feature of the course was its rapid pacing and the corresponding level of focus that was required from all involved. DSI Junior Science students seemed to have internalized the notion that there was no time to waste. The course met after lunch, and I would often arrive to campus in time to see students laughing and chatting as they walked the short distance from the dining hall to the science building, but I noticed that students were consistently prompt for class, seated at their lab tables and bringing their conversations to a close in the moments before Lily called the group together. In part because there was so much material to get through and in part to keep on a similar pace with Julio’s class, lessons appeared to be designed with precision and Lily rarely deviated from the set agenda. During lectures, students occasionally asked clarifying questions, but for the most part, Lily delivered content while students quietly recorded information on handouts that were designed to scaffold their note-taking. I did not observe opportunities for extended student dialogue or prolonged tangents to explore an emerging topic of interest. Lab days had a similar sense of urgency; there was often only hushed conversation while students worked in pairs to progress with efficiency through the assigned protocol before
The class period ended. Fridays were a notable disruption to the regular classroom culture, as sessions run by the undergraduate mentors involved frequent motion between the two classrooms and the occasional raucous quiz game.

An excerpt from my field notes from the first day of class conveys the typical organizational structure and pacing of a class session in DSI Junior Science:

**DSI Junior Science meets in a lab classroom in the campus science building. I arrive early to introduce myself in person to Lily and discuss logistics. The classroom is arranged with a long counter at the front and four lab tables, each seating four students. I see that Lily has put name cards at the tables to assign seats (organized alphabetically to help with names, since she hasn’t taught this group before). Lily explains that they’ll have a chance to move seats later in the summer.**

Several minutes after I arrive, students start entering the classroom one at a time. They are casually dressed and while they’re not overly talkative, they seem friendly with each other. None of them seems particularly anxious, considering it’s the first day of science class for the summer. It’s the afternoon, so they’ve already had a class in the morning – and of course, they’ve also spent the prior summer together.

Once the students are settled, Lily points out a Do Now that is projected on the screens at the front of the room: “Write down all the lab safety rules you can remember.” The students work on this independently for a few minutes, then Lily takes answers from around the room and fills in the rest to make sure everyone is up to speed.

After the lab safety discussion, Lily provides a few introductory remarks about Junior Science. She asks how many of the students have taken biology already in high school, and nearly all of them raise their hands. Lily explains that the emphasis in this course is on preparing students for college science, so the structure will be a mix of lectures (with students responsible for detailed note taking), weekly labs, and problem sets. She adds that because of the rigor required for college prep, Junior Science will be “less fun” than the class they had the prior summer.

With this, Lily moves into her first lecture. The Junior Science lectures mostly rely on a website (unaffiliated with DSI) that presents animated slides depicting the content, and Lily steps through the slides while providing her own commentary. This first lecture is focused on a historical overview of the discovery of the structure of DNA. Students have been given a handout, which is meant to scaffold their notetaking process; from what I can see, they all appear to be focused and
taking notes. During the few times when Lily asks for responses, students participate, either raising their hands or just calling out answers (for instance, a student recalls that opposites attract, and like repels like). The lecture focuses mainly on Watson and Crick, though it also references several other scientists, including Linus Pauling and Rosalind Franklin, and explains how a number of scientists advanced incorrect hypotheses about the structure of DNA before Watson and Crick finally landed on the correct model. Towards the end of the lecture, Lily briefly addresses the fact that James Watson has been heavily critiqued for his racist and sexist beliefs, though she does not dwell on this topic. Lily concludes by explaining that Watson and Crick’s discovery was critical because knowing the structure of DNA means that you can understand how it’s copied, which is the mechanism that causes offspring to resemble parents.

After clicking to the last slide, Lily looks out at the class and says, “Are there any questions?” As her eyes quickly dart around the room, she confirms, “No,” and moves the class into a modeling activity. The students are tasked with using K’Nex blocks to build a model of a DNA strand and to create a color-coded key explaining what they’ve constructed. The students are given an instruction sheet, markers, and the modeling materials. They have about 20 minutes to do this, working with their table groups, and they will be graded. There is a rubric at the bottom of the handout, which a few students are using to self-check their work (some on their own, another when I point it out to him from my perch near their table after noticing that he is awaiting guidance). By the end of class, three of the four groups have a completed model and key. The final group has figured it out but hasn’t finished building. Lily explains that the students will have five minutes at the start of class tomorrow to wrap up, and then the mentors will walk around and grade the models while the students prepare for their lab.

While the DSI course structure was designed with the goal of providing students with the support they will need down the road, Lily expressed dissatisfaction with the rigidity of the curriculum in its current state. “DSI is so unique in that we have so much freedom and a practically unlimited budget to do whatever we want,” she explained, “and we feel like we are not taking advantage of this to its fullest.” Next summer, Lily and Julio intend to revise the Junior Science curriculum to incorporate more authentic inquiry, though they are concerned about how much they will be able to accomplish with students given the time constraints of a summer course. “I would love to see students do independent research projects where they design and carry out an experiment of their
choosing,” Lily said. “But honestly, what can they really accomplish in five-and-a-half weeks? It would be a logistical nightmare with 15 different experiments going on. But I think it would be a really valuable experience.”

In particular, Lily hopes that moving away from predetermined lab procedures with expected outcomes and introducing more authentic experimentation would give students a better understanding of the role that failure plays in science. For now, however, Lily acknowledged that the course readings and lectures give students some exposure to the nonlinear process of scientific advancement by incorporating stories about important scientists and their experiments:

I love the way these side stories open up discussions about the nature of scientific discovery. . . . So much of it was trial and error and I think it’s neat to show kids that even the big names, [like] Linus Pauling, could be so wrong! Back to failure, if I can just get kids comfortable with the fact that things don’t come easily, especially in science, that would be a great victory. . . . I do think that these days, it is more useful for kids to understand the nature of scientific discovery than to know a whole bunch of facts. They will never retain all the facts, but if they can apply the scientific method to everything they do, and ask the right questions, and isolate the variables, and examine the evidence, they are in good shape to be critical thinkers and informed citizens in society.

Research Question 1: How did students engage with the instructional experience in DSI Junior Science, which was intended to facilitate their understanding of the individual as connected to something larger than the self in the ways described above? DSI Junior Science students understood connectedness largely in the context of similarities or relationships between organisms at a global scale, as well as in the context of their own membership within the scientific community. The DSI curriculum introduced genetics concepts through a series of lectures and labs primarily focused on non-human organisms. In their lab work, students extracted DNA from strawberries, conducted a bacterial transformation, and tested self-collected ant
specimens for Wolbachia, a parasite commonly found in insects. Where possible, Lily attempted to comment on the human implications of the phenomena students were studying in their labs – for instance, scientists are currently exploring the possibility that Wolbachia may be useful as an antidote to diseases like malaria, and bacterial transformation has many real-world applications in agriculture, medicine, and environmental health. In the last week of class, the curriculum shifted to a more direct focus on humans, as students engaged in a case study about lactose intolerance and its implications for public health and the dairy industry. Student comments, especially in the double-entry journals (DEJs), indicated their engagement with these ideas about scientific advances and the implications for domains like public health and sustainability. Students were less likely to reflect on their relationships as individuals to the concepts they were studying, though they did discuss personal implications in the context of exploring the possibility that they could become scientists and participate in such discoveries in their future careers.

**Similarities and relationships.** In written work and verbal communication, students expressed an appreciation for how phenomena involving other organisms could relate to or impact humans; as described above, this was primarily discussed at a global level (i.e., focused on humans in general) rather than at a more individual or local level (i.e., focused on themselves or their communities). The DEJs provided a structured space for students to offer reflections on these types of concepts. In their journals, students frequently commented on the similarities between humans and other organisms. Three participants (Alisha, Edward, and Gabby) reacted to a passage in the text explaining that “the genetic code is nearly universal.” For instance, Alisha wrote:
I found this to be an interesting fact because it shows the connection between organisms across the world. Since this world is the only one we know of with living life forms on them, it is interesting to marvel at the connections between every living thing in this world. I think this perfectly back the idea of evolution that took place in the world. Supposedly, bacteria started taking new forms due to genetic mutations and then the newly formed organism took upon more genetic mutations until we reached the place where all creatures currently in the universe are in existence. I think this could explain why we have such similar genetic code to everything else.

Yara expressed a similar sentiment in responding to a different passage about disease transmission in plants:

I connected this to how STIs are transmitted through bodily fluids. The sap is practically the body fluids of the infected leaves. Thus, just as HIV spreads through fluids, the virus of the leaves will too. I found it interesting how similar the transmitting is given the vast difference between leaves and humans. This proves that we are more similar to other organisms than we think.

During the concluding interviews, I asked students to comment on their primary takeaways from the summer, and Fatima and Maria’s responses both focused on what they had learned about the complexity of relationships and interconnectedness in the environment. In her summary of what she had gotten out of the course, Maria explained:

I feel like everything has an environmental effect, whether it’s good or bad. ... Of course that goes for dairy products, but it would also go for any other product that’s being made. So I guess it kind of helps to understand [from the lactose intolerance project] that everything is harmful. [laughs] I feel like the lactose intolerance, that whole topic, helped me see the cause and effects of things. ... And then also the Wolbachia lab, that’s also something you would see happening. And I guess it’s sort of an environmental effect, I mean, if a lot of people get sick, that’s a very huge problem. So I guess even little things like that have a bigger connection that one might not realize until it’s a serious problem.

Fatima’s response also focused on what she had learned from the Wolbachia lab:

I think the Wolbachia [lab] was really interesting because I’ve never heard of it before, and it’s really important to know about it, because it can affect the whole ecosystem, because the ants are a part of it. ... I just found, not even the lab, but just the topic itself, really, very interesting but also concerning that I hadn’t heard about it before. And I feel like that should be a lab everywhere, because it’s a really important issue that there’s not a lot of attention to it. ... Even if ants get it
and other insects, even if they’re insects and we don’t like them, they’re still a big part of our ecosystem. I don’t know how similar it is to the bee problem, but like, if all the bees die, then the whole food supply or food chain will be affected in a negative way. So it’s really important to think about that.

Unlike the other two students I interviewed, Karim’s responses to questions about key takeaways and the concept of connectedness were centered on social relationships rather than the scientific content of the class. Like Maria, Karim found value in the case study, but his rationale for why the project felt meaningful was because he could use his new knowledge about cultural differences in lactose intolerance as a conversation topic to “get to know more people.” When I asked Karim more explicitly whether he had learned anything in the course about connectedness or relationships within a system, his mind went first to social dynamics and his group’s communication breakdown during the case study: “When I do a lot of group work, I like to communicate with people, and when we don’t communicate, it almost annoys me, because we’re not going to get the work done the right way … so it’s like a chain.” In response to whether these concepts had also appeared in the content of the class, Karim took a long pause before shaking his head and responding that he was “not really sure about that, to be honest.”

Notably, while many of the students did articulate implications of the course content for medicine or ecology, these implications tended to remain at a fairly general level. Students were not prompted during the course to extend what they had learned about the human influence on the environment to the subsequent step of identifying actions that they or their communities could take to have a positive environmental impact. Perhaps unsurprisingly, then, the takeaways they articulated – both in

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7 Lily had introduced variation in lactose intolerance (particularly the high frequency of the condition among Asians) as a notable example of how cultural differences in dietary and agricultural practices can lead to observable differences at the genetic level.
assignments like the lactose intolerance case study and in concluding interviews – were focused on the current results of collective human activity rather than specific behaviors that could change outcomes.

**Positioning of the self.** The DSI lectures, activities, and assigned readings did not tend to emphasize or invite reflection on students’ own position or role within the systems and phenomena they were studying; as such, students rarely took this individual stance in their DEJs or in-class dialogue. Thus, I used the interviews as an opportunity to investigate their understanding more explicitly. Students’ responses suggested that while they were intellectually aware of their relationship to the biological and environmental phenomena addressed in the course, those relationships were not always intuitive or at the forefront of their minds. For instance, in our initial interview, Karim applied the same social framing described above in response to a question about whether he tended to think of himself as part of the scientific systems he studied:

> I’m not really close to wildlife, like, the wild wildlife like the jungle, but I am a human, so I do have connections. I do have a chain, but not like an animal chain, but a kind of chain, [because] I connect, I rely on something to help me continue to live. Like food – I need that to live, and water. And something else needs me to live. Like, how can I say...like, my mother. She relies on me to do a lot of things.

Fatima explained in our concluding interview that while she could clearly envision some of the phenomena she had learned about, such as DNA unwinding and unzipping, other aspects of the content felt more abstract and hard to visualize in her own body: “Parts like stuff entering and leaving the nucleus, I guess that part felt more like in a vacuum, just because I can’t really imagine that that happens every single time.”

Meanwhile, Maria said in our concluding interview that she had not approached the
Junior Science content with a “mindset” that encouraged reflection on these personal connections:

I mean, I know it exists inside my body. I didn’t think of it like that, though. Not when I was learning it, at least. It was just like a broad idea or concept of something. … I feel like it’s just the mindset you have when you’re learning it, and at least mine, I wasn’t thinking of it like that. But if you go into that lab or that whole concept trying to learn it, and you think about it like, okay, I’m gonna learn what’s inside of me, I feel like, it’s just the mindset you have in order to learn it.

**Connectedness to the scientific community.** Though students were not often prompted to reflect on their individual roles as participants within natural systems, they were frequently invited to envision themselves as participants within the scientific enterprise. DSI students appeared to understand science as a collaborative community that spanned generations, to see themselves as current participants in that community in their capacity as students, and to envision themselves as having the potential to “officially” enter that community in the future as professional scientists – a finding that mirrors the perspectives of the professional scientists in Study 1 who expressed appreciation for how their work built on the accomplishments of those before them and would inform those to come in future generations.

At DSI, Lily regularly encouraged this mentality in her instruction. For instance, in her lecture setting up the Wolbachia lab, Lily suggested, “Maybe one day, you will help discover other new microbes and their applications.” A week later, after explaining the process of how restriction enzymes are used in targeted gene therapy, Lily concluded, “That is the future, and I hope you can be part of it, as researchers and scientists.” There was little time built into class sessions for student dialogue, so students did not tend to respond verbally to such comments from Lily during her lectures. However, one moment
during a mentor-led seminar stood out as an instance where several students – particularly Alisha – engaged explicitly with the idea of becoming scientists, as documented in this excerpt from my field notes:

*I hear students in multiple groups asking questions about what happens to DNA over time – essentially, they are wondering whether it gets old and/or worn down over multiple rounds of replication. After several unsatisfactory answers, one mentor eventually tells her group about the concept of telomeres, the ends of which become shorter with each cell division. Alisha’s eyes widen upon hearing this news. “So if we stopped that from happening,” she questions, “we could live forever?!” The mentors aren’t certain whether or not to endorse this conclusion, but it doesn’t matter – the students are fully committed to the idea. As if they’ve just been led to the fountain of youth, they buzz with excitement. A mentor calls out from the other classroom that it is time for the groups to rotate. “Guys,” Alisha says emphatically to her classmates as they travel across the hallway, “together we all have to go into science so we can figure. This. Out.”*

More broadly, the theme of being part of a scientific community emerged in students’ DEJs, where they had the opportunity to respond to stories about scientists and their discoveries. Alisha, Edward, and Yara used language suggesting they saw themselves as part of a lineage extending back to the famous geneticists of the 20th century and into the future, where they might themselves hold careers in science. In response to a passage about the trial and error involved in Watson and Crick’s discovery of the double helix, Yara wrote:

*This solidified the philosophy Lily was trying to instill in us that taking risks is a significant part of the process to great discoveries. Watson and Crick found the structure of DNA through many trials and experiments, so if they did it, us students who don’t have as much on the line, should not be that afraid of risks.*

Likewise, Edward responded to a passage about new applications of biotechnology research:

*After the finding of the applications, there has been many exciting developments in technology that could help treat people for their diseases or even for just cool science. There are still many things we don’t know about the world and that’s*
why we young scientists have to go out and find them so the world can know about it and pass it on to the future generations.

Alisha wrote about how reading about how two scientists had built on the work of their predecessors informed her understanding of the role of teamwork:

Here is a real world example of how two people, Meselson and Stahl got to their conclusion by looking at the work of Watson and Crick. This makes me think of how when I am in school, teachers emphasize the importance of teamwork and how no one can get to any conclusion without the work and discoveries of others. I knew that was true because we would not be able to learn about concepts unless someone taught it to us, and someone had to teach it to the person that taught us as well. However, this example of these teams of scientists is a more direct example of this. It shows how in specific fields of study, people build off of others’ ideas, not just simply in the classroom like I have been thinking about for a while. This quote really made me more conscious of the importance of others’ work and importance of communication in real careers.

In their DEJs, student comments about joining the scientific community typically took the form of vague references to possible careers in science. In interviews, where I had the opportunity to ask more explicitly about students’ career ambitions, all three participants said they had not ruled out the option of pursuing careers in science or other STEM fields. Fatima said she had experienced some poor science instruction that had “killed [her] passion a little bit,” but still planned to take a biotechnology course at her high school in the fall because “it prepares you for the real world, and you can do lab science in college after it.” Maria was interning at a local hospital and thought she might pursue a medical career, though she expressed concerns about her abilities to progress through the advanced schooling: “I know it’s a really, really hard course to have to go from bachelor’s, to med school, and then you’re in a room with a bunch of people that love the science, and I’m still struggling to understand it.” Meanwhile, Karim was considering careers in game development or information technology alongside other opportunities in business or fashion, and said that his decision would likely be informed
by how engaging he found the relevant coursework: “I don’t want to just sit down, take
notes, listen to lectures every day. I want to do something hands-on.”

Research Question 2: In what ways, if at all, did the engagement exhibited by
DSI Junior Science students appear to be transformative? Students in DSI Junior
Science often demonstrated moments of transformative engagement in their written work.
The DEJs provided one structured mechanism for capturing student reflections on their
own engagement because of the nature of the assignment prompt; students were explicitly
encouraged to use sentence stems like “This reminds me of…”, “This is important
because…”, and “My thinking has changed…”. Additionally, participants expressed
instances of transformative engagement in our interviews and occasionally in dialogue
during class sessions. As elaborated below, instances of transformative engagement in
DSI Junior Science were most commonly characterized by motivated use and experiential
value.

Evidence of transformative engagement overall at DSI. Of the instances of
transformative engagement I identified from students at DSI, approximately 41% were
characterized as motivated use, 26% as expansion of perception, and 32% as experiential
value (it is important to bear in mind that some instances were characterized as
demonstrating more than one of these components). Table 3 displays the individual
frequencies of each component by student. The table indicates that the distribution and

8 It is important to note that while students were encouraged to pose metacognitive questions in their
journals, it is less clear whether they pursued answers or applied these reflection skills in other contexts
outside the class. As Lily explained after the course had ended: “I am not sure how many students care
even to get their questions answered, but the really interested ones will have discussions with us and the
mentors informally. … A lot of what we do at DSI is try to undo oppressive habits they have picked up in
school, such as, ‘I need to read this text and answer very straightforward questions about the text,
regurgitate it on a test, and then I will have mastered it.’ That’s why even though I’m not a huge fan of
DEJs, and the kids are not either, it forces them to engage with the text in a very open-ended, vague way,
and this experience in itself is valuable.”
frequencies\textsuperscript{9} of the components vary between the students, including some students who were especially prolific (e.g., Alisha) and some who were especially unforthcoming (e.g., Victor) across all three categories. However, the overall trend of motivated use and experiential value occurring more frequently than expansion of perception is fairly persistent across the majority of participants.

Table 3

\textit{Frequency of Each Category of Transformative Engagement for DSI Students}

<table>
<thead>
<tr>
<th>Student</th>
<th>Motivated Use</th>
<th>Expansion of Perception</th>
<th>Experiential Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karim</td>
<td>4</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Fatima</td>
<td>10</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Maria</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Yara</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Victor</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Edward</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Gabby</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Alisha</td>
<td>17</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>47 (41.2%)</td>
<td>30 (26.3%)</td>
<td>37 (32.5%)</td>
</tr>
</tbody>
</table>

\textit{Motivated use}. For DSI students, motivated use primarily manifested in the connections participants made to scientific concepts that they had learned about in other contexts, including their prior science classes as well as out-of-school settings such as television shows or public science events. For instance, in a DEJ entry, Gabby applied her new understanding of DNA replication to try to make sense of the nature of human ancestry:

\begin{quote}
Is it possible that each and every human being is related to each other in some way? In many generations, people meet new people and create more new people.
\end{quote}

\textsuperscript{9} Given that I had different amounts and types of data from different participants, low frequencies should not be interpreted as necessarily corresponding to lack of transformative engagement; the relative distribution across the different components of engagement is more informative.
All of this had to start from two people; and then those two people had to be made from another previous couple. Is it possible that we can get a phenotype, genotype, or genetic disorder(s) from many generations before? Is it possible that we got some similarities with people from different families and backgrounds (i.e. the Bowen and Betts sisters)?

Meanwhile, in his DEJ, Victor connected what he had learned about the unique properties of viruses to his existing knowledge of evolution:

It’s interesting to note how viruses seem to have a reversed evolution. Evolution is commonly associated with becoming more complex while in viruses they became simpler and lost the ability to reproduce on their own.

Many of the connections students made were in the context of how concepts from genetics could (positively or negatively) impact the environment or public health. For instance, in a double-entry journal comment about bacterial transformation, Fatima wrote:

This reminds me a lot of the new technology surrounding CRISPR and gene-editing, because bacteria being transformed into pneumonia-causing cells seems like bioengineering to me (despite there not being a lab or any scientists doing it / despite it being done by the body itself). I am going to infer that, along with being a benefit to the people who might suffer from diseases predicted in gene markers, technology like CRISPR (which this excerpt makes me think of) can actually sometimes be harmful. I infer this because bacteria are displaying here that transforming (“editing a genome sequence”) might also accidentally lead to creating / shaping a “bad” gene. Therefore, something that is meant to be helpful (harmless) could also turn out to cause harm, just like the “harmless” strain of bacteria became pneumonia-causing cells.

Beyond identifying connections between the course content and their existing general base of scientific knowledge, a handful of students also named specific formal and informal contexts where they expected to apply their knowledge from the course in the future, or where they had already seen occasion to apply it. For instance, in our initial interview, Maria explained that she planned to call on her new understanding of genetic engineering in her hospital internship work. In our final interview, as previously
mentioned, Karim explained that he could envision using his knowledge about lactose intolerance to connect with new friends because it would allow him to better understand the science behind their dietary restrictions. During a period of independent work time in class, Alisha shared with her tablemates that she and a group of friends had inadvertently assembled into a familiar configuration on a recent walk to the dining hall: “We were walking a certain way and I was like, ‘We look like a DNA strand!’ It’s affecting my life!”

*Expansion of perception.* DSI students expressed a number of instances in which the content they were learning in class had opened their eyes to a new way of thinking. As described above, students often used their DEJs to document ways that the course content had reframed their understanding of a scientific phenomenon or enabled them to see the world in a new way. Edward, in particular, frequently reacted to the content with a sense of astonishment, using words like “impressive,” “incredibly surprising,” and “insane” to describe what he was learning. For instance, in response to a passage about the role of telomeric DNA, Edward wrote:

> It’s very fascinating that we have all of these enzymes inside our bodies each having their own unique purpose. If we were to not have Telomeric DNA, then our genes would be eroded and our daughter molecules wouldn’t be protected for DNA damages.

While her language was more subdued, Yara also frequently commented in her DEJs about the new ways she was coming to understand biological phenomena. After reading about a classic experiment in which bacteria and viruses were used to confirm that DNA is genetic material, Yara wrote:

> My thinking has changed because I often only thought of DNA as something that passes physical traits among people so it was interesting to think of the viruses it also transfers and how that shows the power and complexity of DNA. I hadn’t
thought of the other traits of DNA before and often forgot that bacteria is an organism that carries DNA and has similar effects to humans.

Students also remarked in their concluding interviews on the ways their thinking had changed over the course of the summer. In particular, all three interview participants mentioned that the Wolbachia lab had expanded their perception regarding the significance of insects. Karim explained that the lab had opened his eyes to the sheer quantity of insects on the planet (“There are a lot of flies and insects, more than I thought, more species…I didn’t know about that”), while Fatima and Maria both remarked that they had a new understanding of the importance of the health of insects to the larger ecosystem.

Occasionally, students demonstrated expansion of perception during class as well. In the week focused on viruses, students repeatedly returned to the topic of whether viruses should be considered to be living things; from their discussions, it seemed apparent that most students had not previously considered the philosophical dimension of this question. An excerpt from my field notes documents student interest in this topic, as well as the constraints on their ability to explore it during class time:

As one group presents their virus diagram, the students return to Lily’s point from earlier in the week about whether viruses are alive. One of the students refers to viruses as “dead,” to which Alisha responds with a nuanced argument about the difference between nonliving (i.e., inanimate) and once living (i.e., now dead). A mentor, who hears this discussion and perhaps thinks they are off task, tries to shut it down with an assertion that “not alive and dead are the same thing.” Alisha shakes her head, vehemently denying this claim. Eventually, the students return to their poster, but the topic is still clearly on students’ minds – as they’re packing up, Yara muses to a classmate, “Do you think a virus is alive? You can’t kill it.”

Experiential value. DSI students indicated that the new understandings they derived from the course held value for them, both in terms of personal interest or
fulfillment and practical application. As previously described in the methods section, I applied the *experiential value* code to any instance in the data that indicated evidence of either intrinsic or pragmatic value, which resulted in 37 instances of experiential value overall in the DSI dataset. Table 4 displays how these instances broke down between the two components of experiential value. As the table indicates, nearly all of the instances fell into just one of the two categories rather than spanning both.

Table 4

*Instances of Each Component of Experiential Value for DSI Students*

<table>
<thead>
<tr>
<th></th>
<th>Intrinsic Meaning Only</th>
<th>Pragmatic Utility Only</th>
<th>Both Intrinsic Meaning and Pragmatic Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karim</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Fatima</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Maria</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Yara</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Victor</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Edward</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Gabby</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Alisha</td>
<td>6</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>22 (59.4%)</strong></td>
<td><strong>14 (37.8%)</strong></td>
<td><strong>1 (2.7%)</strong></td>
</tr>
</tbody>
</table>

The most common manifestation of experiential value was as solely an instance of intrinsic meaning. Examples of the intrinsic meaning component primarily consisted of students remarking on how interesting they found it to study phenomena that were occurring inside their own bodies and in the world around them. For instance, Maria, who was having second thoughts about pursuing a career in health care, said in our initial interview:
Even if I didn’t get into the medical field, I feel like just having the knowledge of what it is that surrounds us, like, basically everything is science, so just that alone is interesting for me to know, and I’d like to be informed of that.

Maria elaborated that her interest in science stemmed in part from her religious perspective, explaining, “I’m not good at [science], but I wish I were, because it’s so amazing, and so I just want to think about it…I know that everything is science, and then science is basically everything that God created.”

Notably, intrinsic value did not always correspond with positive affect. A number of students commented on their negative emotional reactions to the content they were learning, especially as Lily began to introduce some potentially concerning implications for public health and the environment in the final weeks of the course. For instance, Edward wrote in one DEJ entry midway through the summer:

Integrated viral DNA that never leaves the host’s genome and remains there permanently … is actually a horrific thing to organisms. I would not like for a virus to be in my cells forever. I wonder if this can become deadly.

In her DEJ entry that same week, Gabby wrote:

It’s interesting how small an organism can be, but it has so much power over complex organisms – like humans – that it can ultimately destroy the body if not treated by antibiotics. Another thing that is scary is that, natural selection helps these bacteria become stronger and immune to antibiotics and thus, as it spreads that kind of trait during reproduction, it continues to infect the invaded species and nothing can be done to treat it (as discussed in class).

Meanwhile, instances of pragmatic utility were often related to the ways in which students saw the course as helping them prepare for their future endeavors as students and possibly as scientists. For instance, as Fatima explained in our initial interview, “I like that we have lectures because I feel like it prepares us a lot for college…I’m very glad that DSI is looking out for us in that way.” Similarly, Karim said in our concluding interview that he anticipated being able to apply both the content and the skills, such as
note-taking, that he had learned from DSI Junior Science in his upcoming Advanced Placement Biology class.

Several students also described practical applications outside of academic contexts. Alisha commented in several of her DEJ entries that the course content was helping her develop a better understanding of her own bodily systems and how to stay healthy. For instance:

I think it is important to understand how the information from our DNA translates to one’s body performing certain functions to keep them alive. I think this is important because people need to understand how their body works to keep itself running. I have mentioned this in previous DEJ’s but I still think that’s a huge part of the reason that we even take biology in school. The point is to learn about the human bodies, essentially, our own bodies.

As indicated in Table 4, I observed only a single instance, from Fatima, of experiential value that included evidence of both intrinsic meaning and pragmatic utility. Notably, this instance was not actually in response to content that Fatima experienced in the context of the course itself, but rather to an external science storytelling program that DSI brought students to as part of their broader science program. As Fatima explained:

It was all about how science fits into the real world, like every day. And it’s really interesting how science, it has applications to everything we basically do. And I kind of wish that more science classes touched on that, because I feel like for a lot of kids that don’t enjoy science, it’s really easy to just start hating it because you don’t like learning, or you don’t like memorizing a lot of stuff. But if you show them, like, this is how medicine can help people scientifically, or this is how science affects sound waves or something, then I feel like that would be really helpful to a lot of people. …There was this woman [who spoke at the event], she got divorced from her husband, and then she got into baking bread a lot, so then when she was baking the bread, she started talking about the chemistry of bread, and how it causes the bread to rise. And she’s like, “That’s also how I rose from all the worries I’ve had.” That was really cool.

Evidence of transformative engagement in the context of understanding connectedness. To understand the relationship between transformative engagement and
students’ understanding of the concept of connectedness, I also looked specifically for instances in the dataset in which a demonstrated understanding of connectedness was accompanied by evidence of at least one component of transformative engagement. For the eight DSI participants, there were a total of 25 codes for transformative engagement in the context of understanding connectedness (including some instances in which a demonstration of understanding connectedness was coded for multiple components of TE). Table 5 displays the frequency of codes by component of transformative engagement for each student.

Table 5

*Frequency of Each Category of Transformative Engagement in the Context of Connectedness for DSI Students*

<table>
<thead>
<tr>
<th>Student</th>
<th>Motivated Use</th>
<th>Expansion of Perception</th>
<th>Experiential Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karim</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Fatima</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Maria</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Yara</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Victor</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Edward</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Gabby</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Alisha</td>
<td>4</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>8 (36.4%)</td>
<td>5 (22.7%)</td>
<td>9 (40.9%)</td>
</tr>
</tbody>
</table>

As the table indicates, student profiles of transformative engagement differed substantively. Notably, while the majority of DSI students demonstrated at least one instance of motivated use in the context of understanding connectedness, Alisha’s expression of this component is higher than that of her classmates. This seems to be due to the fact that Alisha largely expressed an understanding of connectedness in the context of being connected to a broader scientific community. Throughout her double-entry
journal, Alisha frequently commented on how scientists – her future self included – would be able to apply the course concepts to research and discovery. For instance, in one journal entry, Alisha wrote: “[E]xperimentation is important for discovery. This could be a potential lesson to those like me who are currently learning how to be critical thinkers and problem solvers.”

Students who demonstrated evidence of expansion of perception in the context of connectedness talked about an increasing realization of how seemingly isolated phenomena result in larger emergent effects on the environment. For instance, as quoted previously, Maria and Fatima commented in our concluding interviews that they were struck by the significant impact of Wolbachia on the larger ecosystem; as Maria put it, “even little things…have a bigger connection that one might not realize until it’s a serious problem.”

Experiential value surfaced in students who expressed appreciation for how the content enriched their understanding of themselves and the world around them. In our concluding interview, Karim said he had developed a general appreciation of how he could use science to understand the world around him because Lily “talk[ed] about how it was important to how we live today.” In his DEJ, Edward gave a more specific example:

This genetic code that scientists ha[ve] discovered is shared throughout all organisms …[I]t is very interesting the thought that we are all almost the same in the cell. We relate to bacteria quite a bit as the functions in them are nearly the same for us.

Research Question 3: Is there evidence that the emotion of awe played a role in the learning process for DSI students, and if so, how are these feelings evoked through the instruction and experienced by the learners? To ensure that we shared a common understanding, I asked interview participants to define the concept of awe and to
discuss whether they had experienced awe in the context of science. Throughout the study, I documented evidence of awe elicited by the instruction, both as described explicitly by the students and as suggested implicitly through their observable reactions and use of language.

**DSI students’ definitions of awe and prior experiences with awe in science.** In order to understand how students were conceiving of the concept of awe, I asked the three interview participants to define the term for me in our initial interviews. It was clear from our conversations that the students I spoke to did not have much experience reflecting on the emotion of awe. In fact, Karim and Maria both initially misunderstood my use of the word and interpreted “awe” to refer to a sound one might make in reaction to something shocking, cute, or pitiful; as Karim explained, “when you’re surprised, sometimes you might not be able to speak, so saying ‘awe’ is more like an onomatopoeia.” Once I reframed the question (“What does it mean to be ‘in awe’ of something?”), Karim and Maria used a similar set of emotion words to define awe: Maria described it as “shocked and amazed” and Karim as “surprised and shocked.” Meanwhile, Fatima recognized the word awe from my initial question; her definition similarly involved amazement, but she also interpreted awe as having a religious connotation:

> Um...worship? . . . Awe is like being awed by something. And I think, this isn’t really science, but like, you’re often awed in religion, because you worship something or someone, and it’s usually like a god, and I mean, that’s, like, literally awesome. . . . It feels like gratefulness, admiration...forgiveness, I guess?

Once we had established the definition of the term and I offered some examples, all three interview participants were able to identify at least one prior instance in their education in which science had elicited awe. Fatima explained that she felt a sense of awe “when I just think about how much work that your body has to do just to keep you alive,”
and Maria shared a story about a friend who frequently awed her with facts about astronomy: “He’ll give me these facts with numbers, like how big the moon is, how big the sun is, and compared to everything, how small everything is…and that of course just makes it a thousand times more awing.” Karim said that he had felt a sense of awe during his DSI Sophomore Science class the prior summer while dissecting a rat: “When you do it hands-on, it makes you feel in awe. Rather than sitting, taking notes on the inside of a rat and its importance.”

**The role of awe in the context of understanding connectedness during DSI Junior Science.** In our concluding interviews, the participants could not explicitly identify any moments in which they had experienced awe over the course of the summer, though they did describe moments where they felt interested or emotionally invested. Given that the students had struggled to conceptualize the emotion in our initial interviews, it is hard to conclude with certainty whether the students did not feel awe during their time at DSI or whether they were unable to identify or articulate instances of it. To supplement the interview data, I also looked for evidence of awe, or emotions approaching awe, through students’ verbal and physical reactions to the content during class sessions, as well as through the language they used to describe their reactions to the material in written work and during conversations.

Overall, students seemed most likely to experience an emotional reaction similar to awe when they were able to reflect on the complexity of the human body. While their responses in problem sets took on a procedural quality – simply providing descriptions of the biological phenomena they had been studying as prompted by the assignment question – the DEJs offered a greater opportunity to acknowledge the fact that these
phenomena were happening inside of real humans. In one DEJ entry, Karim wrote, “It is astonishing to know how fast the human body works, yet we don’t seem to feel what is described in the text.” In a later interview, he reiterated this observation, saying, “A lot of [the content] is new to me, and it’s surprising. Like, it’s surprising that all that can happen in a human system…it’s mind-blowing.”

Students’ comments were frequently related to a sense of scale, often marveling at how DNA was both microscopic in size and vast in number. For instance, multiple students reacted in their DEJs to a passage in the course reading, which informed them that “the 6 billion bases of information in a diploid human cell would fill about 1,200 books as thick as this text.” Yara responded:

I’m picturing a section of the stacks of Darby’s campus library would equate to this amount of books. It’s astonishing that the amount of DNA in the human body would be equivalent to such a large area of space because DNA is something microscopic. Imagine if every cell we had was translated into books. I picture it filling a great[er] space than just one section of the stacks.

Likewise, Alisha wrote:

This confused me at first because I was not sure how I could imagine this amount of books as described in this quote. However, upon further thinking and rereading, I was able to grasp what the author was trying to say. All I can say is, I am truly amazed. That is a large amount of bases! I think that it is really interesting to consider the amount of time and effort that such tiny parts of our bodies do to contribute, just to keep us alive. I know our cells are just microscopic parts of ourselves and they don’t actually technically ‘work’ on anything, but, I still have a newfound appreciation for the way the body works to keep itself (and ourselves) running.

As another example of sense of scale, Fatima reacted in a DEJ entry to a line in the course text explaining that if it were stretched out, “the DNA of an E. Coli cell would measure about … 500 times longer than the cell”:

Wow, this reminds me so much of the small intestine in humans! The small intestine—judging by its name—is pretty small from the outside of the human
body since we cannot actually see it (same with most things in our body that we don’t have a visual connection to). However, according to WebMD, it is actually 22 feet long when it is stretched out. This is just like how the DNA of an E. Coli cell is much longer when stretched out than it seems like it is when it is all packed up in the cell. It’s incredible how the small things in our bodies can still be quite large at full length!

Overall, these reactions seem to suggest that DSI students had opportunities to emotionally engage with the notion that the biological systems they were studying in class were genuine phenomena occurring within their own bodies. Whether these emotions reached the level of awe, as defined in the literature or in the testimony of adults, is less clear.

**Gifford Summer Session: Chem 106**

I will now transition to presenting the emergent findings for Chem 106. As in the previous section, I will begin by describing the nature of the pedagogy that I observed during my data collection, and will then discuss the findings in response to each research question.

**Instruction in Chem 106 was loosely structured, with a focus on exposure to ideas and self-directed learning.** Chem 106 met only three days a week, but for two-hour sessions, making the total in-class instructional time eight hours longer than at DSI. Like DSI Junior Science, Chem 106 was also notable for its pacing, but to the opposite extreme. The class often touched on many topics within a single session, informed by Professor Holden’s plans for the day but frequently adjusted in response to student questions and comments. Within a given class meeting, Professor Holden might show a video clip, review a challenging question from a recent problem set, sit back to observe students pursue a self-directed line of inquiry based on their reaction to the assigned reading, and eventually reassume his position at the lectern to offer concluding remarks
or recite a bit of poetry. On other days, a faculty member from another department at Gifford might deliver a guest lecture, or a student would take the helm to deliver a presentation based on their interpretation of the course content or a topic of their own selection. During almost every class meeting, there was extended time for student discussion that was often only loosely facilitated by Professor Holden. These discussions often originated with an impromptu student question or comment – by the end of the summer, nearly every student seemed comfortable interjecting to ask questions during lectures or presentations, regardless of the speaker.

Chem 106 students were also introduced to examples of well-known scientists, primarily through Professor Holden’s lectures and selected readings that supplemented the main course text. Given the vast scope of Chem 106, nearly any scientist could have been relevant to the content, but in general, Professor Holden chose to highlight scholars whose work interacted with contemporary culture and who were motivated by goals of sustainability. A multi-part lecture focused on James Lovelock and Lynn Margulis, the scientists who formulated the Gaia hypothesis (which posits that the organic and inorganic matter on Earth operates as a singular living system), and several other lectures referenced the work of Buckminster Fuller, the architect and futurist who coined the term “Spaceship Earth.”

As assessments of understanding, students completed traditional assignments like problem sets and quizzes and submitted weekly journals. Professor Holden and his Teaching Assistant, Kiyana, presented the journal assignment verbally in the first week of class, explaining that students should use the exercise as an opportunity to write about something from the course that influenced their thinking each week. Some students used
these journal entries effectively to push themselves and document changes in their thinking, though others seemed to approach them as an exercise in filling the page, writing “what I did this week” summaries that were only tangentially related to the course content.

This diversity of instructional approaches seemed to reflect the fact that Professor Holden was weaving together two – if not more – sets of learning objectives: some aligned with the scientific content as laid out in the assigned readings, and others related to the bigger picture implications of the content. These implications involved ideas about how an understanding of cosmic evolution can inform our approach to environmental science and sustainability, as well as an interdisciplinary framing of science that acknowledges its interaction with contemporary cultural beliefs about ecology, technology use and development, and so on. In an interview after the course had ended, Professor Holden explained:

I guess I like having [these concepts] all in there together, and juxtapos[ing] rudely in front of the students’ faces, what do you do with this? You know? What do you do with this? You have to have some scientific things to grab on to. … Now having taught this course, I feel like the story of the universe and the story of the environment and our addressing its problems are really integrated.

An excerpt from my field notes from the third day of class conveys the expansive nature of the topics covered during Chem 106 class sessions, the frequency of student participation, and Professor Holden’s use of multi-disciplinary instructional provocations:

Over the past few days, the students have been assigned a chapter from the course text about the particulate epoch of cosmic evolution (i.e., the point at which particles first appeared in the universe). Professor Holden reminds students that the particulate epoch is significant for being the crossover point at which particles first appeared. He looks to the class to see what reactions they have to the reading. Dylan responds by sharing an initial observation:
The reading mentioned singularities – the concept of all the matter in the universe together in one place. The laws of physics as we know them might not apply to singularities; astrophysicists might know very little about how singularities work. I just thought that was interesting.

Olivia’s reaction to the reading is about how scientists need to form hypotheses on the subjects without relying on concrete evidence, because they can’t recreate conditions that are similar to the first few seconds of the Big Bang. “There’s no record or evidence of that time,” she says. “You just have to hypothesize – like, just believe that’s what happened.”

Sophie joins the conversation:

In most of the things I read, everything that is something also has something that it isn’t, so that you know what it is. ... Like, I know this pen is moving because I am staying still, but if we were both moving constantly in space, I wouldn’t know if I was moving or the pen was moving. So for time, if there was a beginning of it, then anything before it wouldn’t be possible, because that would still be time, so it’s impossible to conceive of an anti-time. So the idea of a point where things happening started is kind of...

Sophie trails off. Nicholas jumps in to revisit the idea of multiple models of the universe that he discussed in the last class. If the cyclic model is correct, he remarks, “there is no such thing as time.”

Professor Holden acknowledges Nicholas’s comment and notes that there are multiple timelines to consider – the timeline of when things actually happened, of when they were discovered by scientists, and of when the individual, as a student, is exposed to them. Sophie, picking up on the phrase “multiple timelines,” asks:

Is the concept of multiple timelines accepted, generally, or at least considered? Because if time is warped, and there is the ability to reverse time, that seems like there is a tangible past. ... If anybody were to reverse time for some reason, it’s not like they could just reverse their own time, because it’s all one thing.

Professor Holden smiles, responding, “You should do some reading in relativity – your mind is ripe for that kind of experience.” The topic of multiple timelines is discussed briefly, but Professor Holden soon turns back to the readings.

After a break, Professor Holden and Kiyana present an overview of the class assignments, adding detail and clarification to what has been outlined on the syllabus. Once this discussion is wrapped up, Professor Holden concludes the session by reciting several poems from Robert Frost, including “Why Wait for Science”: 
Sarcastic Science, she would like to know,
In her complacent Ministry of Fear,
How we propose to get away from here
When she has made things so we have to go
Or be wiped out. Will she be asked to show
Us how by rocket we may hope to steer
To some star off there, say a half light year
Through temperature of absolute zero?
Why wait for science to supply the how,
When any amateur can tell it now.
The way to go away should be the same
As 50 million years ago we came,
If anyone remembers how that was.
I have a theory but it hardly does.

Professor Holden finishes his recitation and looks to the class for their reactions. Dylan wonders if the “she” in the poem is supposed to be Rachel Carson. Several students suggest that the poem is about the need to escape the planet before its destruction, though Dylan says he interpreted the phrase “get away from here” as referring to dying off as a species, rather than leaving the planet. Professor Holden says that when he read it, he thought of climate change and the need to colonize other celestial bodies, but he concedes that the last part of the poem seems to align with Dylan’s interpretation. Another student observes that the title is cynical. “So kind of a dig at science,” Professor Holden asks, “that it can’t figure things out fast enough to save us?” Sophie responds:

I thought it was kind of a dig at humanity, for sucking. It seems like he’s being facetious – we are already on our way to escaping by our own hand, so we don’t need for a rocket to take us to Mars to die, we can just wait for ourselves to cause destruction.

In reflecting on his instructional approach after the summer had ended, Professor Holden affirmed that letting student interest inform the direction of the course had better served his goals than attempting to stick to a predetermined agenda:

There’s way more material than I can cover. And so my first guess at which topics were going to be sampled didn’t work out, [but] that was fine. Because the things I replaced them with would all be part of the same story, anyway. And you know, you like to be able to let people indulge their curiosity and ask questions or pursue some specific thread that you only barely started, or maybe didn’t even realize you started when you made the assignments. The readings had so much in them, and I don’t know how they did them all. They probably didn’t do them all. [laughs] But it doesn’t matter. It worked. I think it worked.
Professor Holden concurred with my observation that he seemed to prefer laying material in front of the students without offering much explicit commentary about why he was including it. “You go out there and do your thing,” he said, “and some of it will happen to land on your head, or your students’ heads, and it’s a great thing.” While this strategy comes with the risk that students will sometimes miss the opportunity to make important connections, Professor Holden felt that in balance, the subtlety was worth it: “I think those are special moments for the students, when they’ve been sort of primed for some discovery and then they make that discovery sort of on their own.”

Students seemed to acknowledge both the affordances and limitations of Chem 106’s loose structure and broad framing. In interviews, several students commented that the class design was “disorganized” and that at times they struggled with the lack of clear expectations around assignments. In general, however, students also expressed appreciation for the freedom that this flexible structure provided for them to pursue their own intellectual interests within the bounds of the course.

**Research Question 1: How did students engage with the instructional experience at Gifford University’s Chem 106, which was intended to facilitate their understanding of the individual as connected to something larger than the self in the ways described above?** The Chem 106 curriculum, which was designed around the overarching concept of “cosmic evolution,” covered a vast range of content across multiple domains of science including physics, chemistry, biology, and anthropology. Students demonstrated thoughtful engagement with the relationships between these domains of knowledge and the ways they interacted to inform a broader understanding of the universe. A key instructional goal was to emphasize the implications of the content
for humans – the word “humankind” was in the course title – and three enrolled students (including study participants Sophie and Dylan) increased the focus on humans in the final weeks by using their presentations to discuss the concept of consciousness. While Professor Holden’s lectures tended to focus on the implications for sustainability at a global scale, student reflections were often at the level of the individual, especially in their journals and interviews. The notion of belonging to the scientific community was also present in Chem 106, though in a different sense than at DSI; students were more likely to describe themselves as adopting a scientific worldview than to anticipate actually pursuing science as a career. This is perhaps unsurprising given that the college participants were enrolled in Chem 106 to fulfill the single science credit that Gifford required of them as humanities majors. Moreover, while Professor Holden presented scientists as “real people” by incorporating narratives of historically relevant scholars and welcoming guest lecturers, he did not regularly comment on the possibility of Chem 106 students becoming scientists themselves – perhaps due to his awareness that some of the students enrolled may have already opted out of this path.

**Positioning of the self.** Students in Chem 106 regularly engaged with ideas about how the concepts in the course were informing their own worldviews. Students often made a point of incorporating such reflections into their presentations. For instance, in her presentation on biological evolution, Olivia remarked:

> We’re all related from the same way, such as descending from the same eukaryotic organism, or sharing the same molecules. About 50% of our genes are the same as those in fruit flies. If that doesn’t gross you out a little bit and interest you, I don’t know what will.

Dylan and Sophie both chose to focus on existential questions of consciousness in their presentations: Dylan explored the notions of group consciousness that Timothy Leary had
suggested were possible via the use of psychedelics, while Sophie introduced theories
from Eastern philosophy about the relationship between the mental and physical self. In
her concluding interview, Sophie explained how preparing for this presentation had
impacted her differently than the other aspects of the course:

   Honestly, when I was researching consciousness a little more, it gets you into
   this wormhole of thinking about yourself, and thinking about yourself thinking
   about yourself. So it’s just a very perpetual, like, oh my God, what am I, and
   where is the base of me? But when you get to more material things, and
   especially with learning about biological evolution, it just, it’s a lot easier to be
   like, ok, I am something, even if it’s, like, a really weird distance from me.

In contrast, several students in the course took a “just-the-facts” approach to their
presentations. Nicholas took a self-deprecating tone in our interview when I inquired
about his rather straightforward presentation on plate tectonics, saying “Yeah, everyone
picked consciousness, biological evolution, all the very ‘techno’ stuff, and I’m just there
picking rocks.” In the journal entry he submitted after his presentation, Nicholas
commented on how the study of plate tectonics and other concepts addressed in class that
week offered more resolution than the earlier topics:

   It is a decent shift from the other classes as for once, scientists do have some
   concrete answers on these subjects. Granted, some things are still being answered
   but scientists do have a much better grasp on how the events occurred in the
   evolution on Earth compared to the evolution of the early Universe. In conclusion,
   this last week has opened my eyes to some of the more answerable subjects,
   though there are always some questions that are still unanswered.

Thus, despite his self-described interest in unanswerable questions, Nicholas seemed to
find some comfort and satisfaction in these less disequilibrating scientific phenomena for
which tangible answers were available, especially when it came time to present to his
peers.

   Regardless of their presentation focus, all four participants spoke in their journals
and/or interviews about how they saw themselves in relation to the vast, complex
concepts explored in the course. Often, the sentiments expressed by students evoked the
notion of “small self” as documented in the literature (Piff et al., 2015); students
described feeling small, and at times insignificant, but on balance, contemplating these
ideas seemed to be productive for them rather than upsetting.

Learning about the various models of the universe early in the summer seemed to
be particularly impactful in this regard. Nicholas, especially, harbored a deep desire to
understand the competing models for the origin of the universe, and in our first interview
he shared how he saw these models interacting with his understanding of the self:

One of the big things I’ve always been thinking about is what happens before
birth, and what happens after death. That’s a thing I’ve always mused about in my
mind, sometimes during the nights or during the day. Which can be a scary
thought, and it’s definitely a scary thought I had a lot as a kid, and now I have it
more as a scientific teenager, but still, it’s a scary thought. But what I’m trying to
say is, that’s why that connects to my simplified thought of how the universe is
created from nothing, because then it’s just like birth and death. What is there
before, and what’s there after death? … It’s almost the same as how scientists are
trying to figure out maybe the impossible, and that’s the universe. What is
created, and when does it end? And what happens after it ends? It’s almost
impossible to ever know.

By the end of the course, Nicholas’s perspective on the universe seemed to be further
intertwined with his ideas about science as a way of knowing. In our concluding
interview, he explained:

If anything, I don’t feel as connected as I used to, to the world and to space. And
that’s not a bad thing, I think, it’s just, you know, a realization. We’re all very
small, we’re all very tiny in the grand scheme of things. … I can be on a small
scale on the planet, [and] in terms of the grand scheme of things, it’s like, what, a
speck. Not even. But with that understanding, you can become more connected to
the sciences, to the methods, and then to the universe itself, while at the same time
realizing that you’re not that connected to it. I think it’s a very weird, how do you
call…a tug of war, let’s say.

The other three participants shared similar sentiments in our interviews about
feeling small in relation to the universe. For instance, Olivia remarked in our initial interview:

I feel like the topics we’re talking about are just about things that are so immense – the universe itself is huge, huge, huge. So in order to just digest any of that information, I kind of have to imagine myself stepping away from it, and just looking at it as a whole picture. But at the same time, we’re all part of it, all together, because we’re made of up atoms, or whatever, and we’re made up of – again, another analogy, like those tiny little cells in our body all work together to make us as a whole person. And then we, people, make up societies, communities, and stuff, and then we make up the world. And then that world is a part of another solar system, which is also part of a galaxy, and part of...you know? And so on and so forth.

Sophie grappled in our initial interview with the ramifications of thinking about her position within these vast systems:

I feel like the more removed I make myself, the worse it gets, because if you feel like you’re just this isolated thing that is unconnected to anything, it can feel pretty dreadful … I’ve definitely had times when it’s made me feel small and irrelevant. And that can be a bummer. It’s hard to get out of a spiral of thinking nothing I do matters, because it’s so small. But then it also does matter, because if everything is connected, that means every single tiny thing is connected, so just getting out of the bed in the morning changes the prospect of everything in my day. So that’s kind of helpful to me, in that way.

By the end of the course, Sophie seemed to have reached some level of comfort with this sense of disorientation, explaining in our concluding interview that “I’ve learned that I can deal with, and find it interesting to be in, both of those states of mind.”

Dylan, meanwhile, explained in our concluding interview that the guest speaker on anthropology had evoked particularly strong feelings of connection for him:

I thought there were only like three species of pre-humans when in fact there were at least a dozen. So that, I felt a lot more, I don’t know, I felt like a part of something greater than myself. Just because when we think of humans as a species, we just think, oh, there’s one Homo sapiens sapiens species, and it’s not really a cause for unity because it’s the only species. But when you’re looking at it through the lens of, there actually were like a dozen species, then you kind of feel more unified under the banner of Homo sapiens sapiens.
More broadly, Dylan explained that the course was contributing to an ongoing process of opening his mind to ideas that fall outside his field of expertise. This was a recurring theme throughout his journals, but even in our initial interview, he described how the course had already begun to change his perspective:

I can think more about just how infinitesimally small the earth is in the grander scheme of things. It recontextualizes everything that we’re doing here. And I think especially as, you know, the only thing that I really am studying is the saxophone, which is an extremely small piece of an extremely small planet. I don’t know how to describe it. But this class is changing my perspective as far as how much more there is than just the saxophone.

When I asked how this perspective shift made him feel, Dylan responded with a laugh, “It’s definitely exciting, but I’m still not where I want to be with the saxophone. So I figure, get that where I want it to be first, and then worry about the universe.”

**Connectedness to the scientific community.** Students in Chem 106 regularly described a sense of adopting a scientific mindset, both within and outside the context of the course. For instance, in her first journal entry, Olivia expressed appreciation for Professor Holden’s instructions that students should take a scientific approach to the reading assignments (i.e., asking questions of the text and searching for evidence to support their ideas):

Perhaps I must alter my methods in reading from now on because I haven’t been using the “scientific method” or viewing through the lens of a scientist or thinking much like one whilst reading these academic texts. As a result of this new method of reading, I found that I am much more efficient at nitpicking only the important details and actually having the information stay in my mind.

Nicholas felt that the course was helping him become conversant in what he saw as a set of important modern scientific theories – in general, this seemed rooted in a basic desire to be well-informed, though he also indicated that this knowledge might be useful in a
future career path. In his second journal entry, he positioned himself (and his generation more broadly) as part of the scientific community:

After learning about the Galactic and Stellar Epochs, my opinion on the whole matter still stays quite the same. Scientists don’t have enough to make many conclusions. However, I do enjoy that greatly about this subject. It allows the people learning about these theories and mechanics to have our own thoughts and even come up with our own theories about how galaxies and stars are formed. In my opinion, that is much more enjoyable and interesting than just having facts that are all already known and proven to be piled into someone’s mind for memorization. In this case, there are questions still to be answered and theories still to be proven and it is up to us, the next generation, to step up and eventually take the place of our current scientists to try and figure out the hard hitting questions of the Universe.

Sophie said in our initial interview that she had not ruled out science as a career path, and while she thought she would more likely pursue the humanities, she appreciated the opportunity to think like a scientist during the course:

I love the types of discussions we can get into, where it’s like, what if this happened? And then we explore what would happen if that was. I really like the hypothesizing and theorizing, because it makes me feel more like a scientist, I guess.

By the end of the summer, it seemed that Sophie’s ideas about the value of science as a career had become significantly more complicated, as demonstrated in this conversation from our concluding interview:

Sophie: I felt like I went into this class trying to see if I would want to pursue a more science-based path at school, which, like, towards the middle of the course I was feeling like, yes, I totally do, because it’s really interesting. But also in many ways it makes me feel like I’m thinking about life as opposed to living it. So it’s like a very difficult trade-off for me. And it does feel like a trade-off in that sense. But...

Interviewer: Do you mean that choosing a science field as a major would be thinking about life versus living it?

Sophie: Well, I guess, yeah. Like, if I wanted to go be a scientist, I think I would be extremely interested in all of the stuff that I would learn, but at the end of the
day, am I actually living the life that is presented, or am I just learning about what it is, you know, through a job like that?

**Interviewer:** Hmm. What’s an example of an academic or professional path that you feel like does not fall into that category? Where you feel like you’re living?

**Sophie:** Oh. Hmm. Well, I guess that’s a good question. [laughs] ‘Cause... I don’t know, I guess I always pictured a contrast between if I were to study neurology and go into brain science and start just looking at the brain and determining why it does a bunch of different stuff, as opposed to using my brain to, like...write movies, or something. You know?

**Interviewer:** Yeah. Does it feel like it’s about the work that you’re producing, or the impact it’s having, or...?

**Sophie:** I think it’s a personal thing. Like, obviously if you learn about the world more, it contributes to humanity a lot more. Whereas taking on a more creative job feels more like a personal, what makes me happy and comfortable. So...but I guess, on levels of importance, it might just end up being, like, more important, big picture, to be doing something to make the world last longer, as opposed to – not that I have that ability, but just that it’s important to probably work towards that.

The experience of Chem 106 seemed to stir up challenging feelings for Sophie regarding her potential membership in the scientific community. As reflected here, by the end of the summer, Sophie had developed complicated – and even contradictory – ideas about the value of a profession whose purpose is to investigate the workings of the universe.

**Connections across ways of knowing.** Each of the four participants commented in journals or interviews about the nature of science as a discipline and the connections between branches of science or between science and other domains. While not directly related to students’ understanding of the self in relation to broader systems, this perspective did seem empowering for students in terms of their ability to engage with the concepts through different disciplinary lenses. The idea of interdisciplinarity was especially salient for students because of Professor Holden’s instructional approach; most of the students seemed pleasantly surprised by his decision to incorporate the arts into his
instruction and appreciated how this helped them see the connections between different ways of knowing. Dylan, a music major, said in our initial interview that “I think of science and music as these two distinct spheres that will never interact. But I’m sure that if I thought about it, there’d be some connections.” In our concluding interview, Dylan shared that the interdisciplinary nature of the class was the most impactful element for him:

The course material in and of itself probably won’t change anything for me, but the interdisciplinary nature of it, I think, definitely…you know, I’m taking a philosophy class next semester. I can take that and think to myself, you know, it doesn’t have to be exclusively philosophy that I can use to study this course material. I can grab things from other disciplines, and it’s not a strictly separate thing like I thought it was before I took the course.

Olivia remarked on the last day of class that she now saw more “interconnectedness with the material” because of how the humanities had been incorporated, and Sophie said in our concluding interview that the course content had provided her with new inspiration for her own art.

Nicholas spoke less about the role of the arts, but he commented frequently about his appreciation for the relationships between various branches of science. In our initial interview, Nicholas explained that while he hoped to become a biologist, he had decided to take Chem 106 because he felt that understanding the physical sciences would also be useful to him: “I think one of the best ways to get an overall sense of the sciences is definitely to do [cosmic evolution], because that covers so many types of sciences, and that can lead and branch off to the other types of sciences.” When I asked about the concept of connectedness, Nicholas’s mind returned to this disciplinary perspective:

It’s actually strange, now that you mention it, I think it’s a theme that’s always in studies, I feel, that’s always just there. Everything is connected, everything has been, and that’s why it’s important. … If I get to do these sciences that may not
pertain mainly to the sciences I’m doing, they will connect to the sciences I want to do and help me boost some part of that science and actually get me a step forward, even if it’s not directly related. …There are theories that can connect to other parts of the scientific world.

Throughout the summer, Nicholas continued to reflect on the idea that many scientific problems required interdisciplinary approaches. For instance, he noted in his fourth journal entry that “this course has been able to open my ways into many fields of science that are essential to figuring out the key questions floating around among the scientific community.”

Sophie’s comments demonstrated that she, too, was thinking about the interaction between different branches of science. During a class discussion early in the summer where the students were signing up for presentation slots, Sophie challenged the premise that the subject matter could be broken down into discrete topics, musing, “How can we possibly do any of these without talking about the rest of them?” She expressed a similar sentiment in our concluding interview when I asked her to identify a key takeaway from the summer, saying, “I don’t know, because it feels like I can’t have any of it without the rest of it.”

**Research Question 2: In what ways, if at all, did the engagement exhibited by Chem 106 students appear to be transformative?** Students in Chem 106 demonstrated moments of transformative engagement during class sessions, in our interviews, and in their written work. Overall, transformative engagement was not especially evident in the Chem 106 journals, perhaps as a function of the lack of specific prompts to guide student writing. However, there was frequent evidence of transformative engagement during class discussion: Chem 106 involved regular episodes of lengthy classroom dialogue with
only light facilitation from Professor Holden, which presented frequent opportunities for
students to express their engagement with the material.

As elaborated below, instances of transformative engagement in Chem 106 were
most commonly characterized by expansion of perception and experiential value.

Evidence of transformative engagement overall in Chem 106. Of the instances
of transformative engagement I identified from students in Chem 106, approximately
23% were characterized as motivated use, 40% as expansion of perception, and 37% as
experiential value (again, it is important to bear in mind that some instances were
characterized as demonstrating more than one of these components). Table 6 displays the
individual frequencies of each component by student. The frequencies and distribution
patterns vary across these students, though the general trend of motivated use being the
lowest category holds true for all four participants.

Table 6

Frequency of Each Category of Transformative Engagement for DSI Students

<table>
<thead>
<tr>
<th>Student</th>
<th>Motivated Use</th>
<th>Expansion of Perception</th>
<th>Experiential Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sophie</td>
<td>9</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Dylan</td>
<td>4</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Nicholas</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Olivia</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>18 (23.1%)</td>
<td>31 (39.7%)</td>
<td>29 (37.2%)</td>
</tr>
</tbody>
</table>

Motivated use. In their journals and our interviews, Chem 106 students described
ways they had applied their learning from class to other contexts. Additionally, students
were invited to use the class presentation assignment to apply the course content to a
topic of personal interest; some students took significant advantage of this opportunity
while others stuck more closely to the course texts. Sophie, who demonstrated more
instances of motivated use than her classmates, saw frequent opportunities to apply the course concepts to her art. In our initial interview, she explained that she anticipated drawing on the content “as a topic or thing to explore through drawing or filming something…it’s kind of cool to make something that is based on reality as we know it, as opposed to just painting a fruit, for example.” This manifested in Sophie’s presentation on the nature of consciousness, for which she produced drawings to illustrate her ideas about the substance of brain waves and emergent collective consciousness; similar drawings appeared in several of Sophie’s journal entries. In our concluding interview, Sophie confirmed that she had in fact been inspired to create art based on the ideas from the course:

I just feel like once I took this class I started wanting to read a bunch more. There’s so many things related to passage of time, and our minds, and space, even, that are so interesting, that I realized I have a taste for. And so there’s a lot more content for me to take in, and …it feels like it’s definitely contributed to some of the art I’ve done, or at least made me want to do art more.

Class dialogue also presented an opportunity for students to draw connections between the course content and other ideas of interest or about which they had prior knowledge. For instance, in her presentation on natural selection, Olivia introduced the biological concept of the “selfish gene” and related it to the philosophical concept of “veneer theory,” which suggests that human culture provides a thin mask for an inherently selfish nature. After this presentation, Nicholas probed further, seeking connections to his understanding of the concept of pacifism:

Going back to the veneer theory and whatnot…what is your opinion on pacifistic humans? Is that a genetic difference to other humans? Because if this theory is true, it’s basically a veil over our animalistic nature. So is pacifism a defect?

After pondering Nicholas’s question, Olivia responded by drawing a further connection
to her own existing conceptual framework:

It might have been part of the genetic code of our ancestors, but nowadays I think it’s more dependent on how you were raised, and the culture. To give an example: filial piety, it’s a Confucian teaching. I was taught to care for your elders and parents. It’s just kind of the culture to really respect elders and take care of the young.

Expansion of perception. Chem 106 students described many instances in which the content they were learning in class had shifted their perspective or introduced new ways of understanding the world. As mentioned in an interview excerpt previously quoted, Dylan said that the course was leading him to realize “how much more there is than just the saxophone.” Several days later, he expanded on this point in a journal entry:

I am a music student. I spend most of my school year practicing and creating small compositions for class. After two semesters like this, I have a bit of a one-track mind. The first reading we were assigned in class, which dealt with cosmology and the scale of the universe, was very eye-opening for me. For the first time in years, I stopped and examined my goals in a larger context. Not only am I focusing on one thing amidst a world of possibilities, that world is infinitesimally small within the larger context of the universe. Although studying music is still my first priority, the course material is forcing me to look around and consider the billions of years of galactic evolution that have given me the opportunity to live, let alone study music or anything else. I hope the future course material will continue to help me recontextualize my goals.

Other students also reflected on how the course was introducing them to new ways of learning. Sophie explained in our initial interview that while she had previously studied literature and art history in high school, she had never thought about how the people creating art in the past were also influenced by the contemporary scientific advances happening in their lifetimes. For instance, she noted that learning about Robert Frost’s interest in astronomy made the experience of analyzing his work “actually completely different…it was interesting to re-read it and have that perspective.” More broadly, Olivia explained in our interview how this course and the other summer course she was taking at
Gifford shifting her understanding of being a learner:

These college classes are giving me a whole new experience and perspective of what it’s like to be a different type of student . . . a different type of learning, I guess? Because high school, you know, they just give you homework, you just study, you kind of just follow the book. But this, it kind of forces me to really think about those topics, and really kind of tease these big questions apart.

Experiential value. I applied the experiential value code to any instance in the data that indicated evidence of either intrinsic or pragmatic value, which resulted in 29 instances of experiential value overall in the Chem 106 dataset. Table 7 displays how these instances broke down between the two components of experiential value. Nearly all of the instances of experiential value for Chem 106 students fell solely into one category or the other.

Table 7

<table>
<thead>
<tr>
<th></th>
<th>Intrinsic Meaning Only</th>
<th>Pragmatic Utility Only</th>
<th>Both Intrinsic Meaning and Pragmatic Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sophie</td>
<td>6</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Dylan</td>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Nicholas</td>
<td>5</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Olivia</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>21 (72.4%)</td>
<td>2 (6.9%)</td>
<td>6 (20.7%)</td>
</tr>
</tbody>
</table>

The most common manifestation of experiential value was as an instance of intrinsic meaning. Examples of the intrinsic meaning component primarily consisted of students remarking on how interesting and eye-opening they found the content; many described an appreciation of “learning for learning’s sake” rather than identifying specific applications to their future academic or professional goals. For instance, Nicholas had initially expected the reading assignments to be dense and boring, but in our initial
interview, he described his surprise at how he had reacted to the first few chapters:

As I read, I was like, this is really cool! I really want to see how they came to these conclusions. How is this an open, or is this a closed, or is this a cyclic universe? And what do the particles, that are all neutrons, protons, electrons, have to do with this? What is the Hadron Collider? What are all these things that I’ve heard on the Big Bang Theory? And now I can explain that to myself, what are these things that they’re talking about, instead of just laughing along with the sitcom. And that is a huge thing for me to actually realize that I’m starting to learn. And it’s a huge, that’s one of the most satisfying feelings, when you know you’re learning. It’s more satisfying than any game, I think, in my opinion.

Likewise, in our concluding interview Sophie explained a newfound appreciation for learning:

I think [this class is] just going to inspire me to do a lot of other things. I think it will motivate me to want to learn more, because I mean, I guess before this class started I felt like I was kind of very ambivalent about living up here and going to college in summer. But I actually am learning from this class that I like learning. ‘Cause it’s just, it’s interesting stuff. It makes your brain tick. And so I guess I’m excited to see what other thoughts it will provoke, and conversations.

Intrinsic meaning was not exclusively positive for Chem 106 students. Students’ descriptions of how the content had personally impacted them, some of which were quoted above in the section on positioning of the self, also included elements of fear or insignificance.

Though most of the students focused on the intrinsic personal impact of the course, several did identify more pragmatic uses for their future learning. For instance, Nicholas noted that, should he stick with his current plans to pursue a science major in college, “this would be an enormous help to me, and it would definitely be like the groundwork, the framework for what I’m looking for. And I can even look back at some notes and stuff.” Olivia similarly expected to apply what she had learned from the course in her future science courses in high school and college.
Evidence of transformative engagement in the context of understanding connectedness. As with the DSI students, I also looked specifically for instances in the Chem 106 dataset in which a demonstrated understanding of connectedness was accompanied by evidence of at least one component of transformative engagement. For the four Chem 106 participants, there were a total of eight codes for transformative engagement in the context of understanding connectedness (including some instances in which a demonstration of understanding connectedness was coded for multiple components of transformative engagement). Table 8 displays the frequency of codes by component of transformative engagement for each student.

Table 8

Frequency of Each Category of Transformative Engagement in the Context of Connectedness for Chem 106 Students

<table>
<thead>
<tr>
<th>Student</th>
<th>Motivated Use</th>
<th>Expansion of Perception</th>
<th>Experiential Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sophie</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Dylan</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Nicholas</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Olivia</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>2 (25.0%)</td>
<td>2 (25.0%)</td>
<td>4 (50.0%)</td>
</tr>
</tbody>
</table>

These frequencies are too small, and too varied by student, to discern any course-level patterns of transformative engagement in the context of understanding connectedness in Chem 106. Overall, however, student engagement occurred in both of the domains identified above regarding how Chem 106 students thought about connectedness: in the context of connections across ways of knowing as well as in the sense of one’s position to something larger than the self.
In the disciplinary sense, Nicholas returned several times throughout the course to discuss his developing understanding of “connectedness in the studies.” As previously quoted, Nicholas expected that the topics in science he was learning about in Chem 106 would “connect to the sciences I want to do and help me boost some part of that science and actually get me a step forward, even if it’s not directly related.” Meanwhile, while Dylan did not expect to take additional science courses, he still saw opportunities to apply the interdisciplinary approach of Chem 106 to his future work in other domains, as noted above in his observation about how this perspective might be useful in his upcoming philosophy course.

In addition to these disciplinary applications, students expressed an intrinsic sense of interest in learning about their relationship to the universe. For instance, as quoted previously, Sophie described in our initial interview a sense of paralysis that can accompany the realization of one’s own insignificance. At the same time, she acknowledged the value that she saw in this understanding:

> When you think about how much had to happen for any given thing to happen to you, it’s pretty amazing. And it also does make it feel like, oh, I’m in it with everybody, no matter what happens. And so there’s always connections you can make with other people or, you know, dogs, for example. [laughs] There’s just so many strings connecting everybody that it’s, I think, pretty cool to learn about.

**Research Question 3: Is there evidence that the emotion of awe played a role in the learning process for Chem 106 students, and if so, how are these feelings evoked through the instruction and experienced by the learners?** As I did with DSI participants, I asked Chem 106 participants to define the concept of awe and to discuss whether they had experienced awe in the context of science to ensure that we shared a common understanding of the term. Throughout the study, I documented evidence of awe
elicited by the instruction, both as described explicitly by the students and as suggested implicitly through their observable reactions and use of language.

**Chem 106 students’ definitions of awe and prior experiences with awe in science.** When asked to define the term “awe” during our initial interviews, the Chem 106 students offered some definitions that included elements of surprise and amazement. For instance, according to Dylan, “awe is something that captures your whole attention, so that you’re not thinking about anything else when you’re in awe of something.”

Similarly, as Nicholas described:

> Awe is like surprise and wonder, in my opinion. Like, you look at a piece of art, and awe...I think just beauty and astonishment and just being impressed, I think, is the main thing I think of when I think of awe. I think impressive.

However, the Chem 106 students’ definitions went beyond surprise and amazement to incorporate additional elements. For instance, Sophie’s definition included a sense of curiosity:

> I mean, I know exactly how it makes me feel when I’m in awe, and it’s just like, I don’t know. [mouth agape] The face you make when you say, or when you think it. Yeah, I guess just amazement, but also wonderment, probably a lot of curiosity involved. I think whenever I’m in awe, I have a million questions all at once. Which is something that’s definitely happened, especially with learning about time. Because I grasp a little bit, but it also doesn’t make any sense, because it’s so conceptual.

Olivia’s definition also touched on this sense of curiosity, as well as an element of novelty:

> It’s when I’m just kind of dumbfounded at the grandeur of anything at all. It’s just anything new that is just foggy at first, but then I’d be curious to learn more about, so then I just dig in, and then when I dig in, like, just a whole bunch of information comes at me, and I’m like [mouth agape] okay, that’s a lot, whoa. You know? … Something I’m interested in, I might look into it for a couple of days or something like that. Maybe read a book about it. But then if I’m really surprised by something, it’s almost like an obsession that I just have to keep going, and keep searching for these answers.
Later in my initial interview with Dylan, he also suggested that there is a component of novelty to awe, explaining, “Once there is a new experience that I’m in awe of, I can usually revisit it at least a few times and still get that feeling, but it does eventually go away.”

After establishing definitions, I asked the students whether they had previously experienced awe in the context of science. Both Sophie and Dylan said that contemplating the size of the universe had elicited a sense of awe for them, and Olivia shared that she had felt a sense of awe in middle school while learning about animal life from documentaries (for instance, “how the embryo of an elephant grows in the womb and grows into this massive animal, when we’ve all just started at that tiny cell stage”). Notably, Nicholas was the only participant in the study who clearly delineated between awe and lesser degrees of interest. He said that he had not yet experienced awe in the context of science, and posited that he would likely not feel it until he had had the opportunity to make a discovery of his own:

I’ve definitely had huge interest in what these theories are and whatnot, but I don’t know if it’s been to awe quite yet … I’ve felt excitement, I’ve felt astonishment, I’ve seen impressive stuff, very impressive stuff that I was just like, wow, that’s awesome. But awe is, I think, way stronger … My theory may be, the one time I will feel connected to something in awe is if it’s something I’ve done that is huge. And I don’t want to sound narcissistic that way. But I feel that may be one of the only ways, in my opinion, that that’s how you’ll feel awe, it’s something that you’ve done. You’re in awe of yourself.

**The role of awe in the context of understanding connectedness during Chem 106.** After establishing definitions of awe, I asked the participants in our initial interviews whether they had yet experienced awe during the first few days of the course; at the end of the summer, I again asked the three students who participated in concluding interviews
whether they felt they had experienced awe during the course. All four students identified
moments of intense interest and emotional engagement, though many expressed
hesitation about when to apply the word “awe” as opposed to other emotion vocabulary.
As with DSI, I looked for supplemental evidence of awe, or emotions approaching awe,
through students’ verbal and physical reactions to the content during class sessions, as
well as through the language they used to describe their reactions to the material.

For Chem 106 students, emotions resembling awe were often elicited in the
context of spatial and temporal scale; many also reflected on the philosophical
implications of the existence of these vast and complex systems. Several students used
the phrase “mind-blowing” to describe their reaction to the course content. As Nicholas
said in our initial interview, “What’s in the readings… the amazing discoveries that
they’re making about how the universe could have been born and what could have been
created, is phenomenal. It’s mind-blowing how they even got to the first place.”
Likewise, Olivia described herself in our initial interview as “mind-blown” by the nature
and quantity of the content she had learned in the first few days of the course, and
“dumbfounded by all these incoming answers for these questions that I’ve always had, or
everyone has always thought about.” This sentiment was reiterated in Olivia’s journal
entry several days later:

It feels as if I’ve learnt so much and yet, at the same time, it’s as if I’ve learnt
nothing at all. Everything that we have been learning so far has been so mind
boggling and immense. My brain just can’t seem to process it all. This class is
much more different than any science class I’ve had the pleasure to be a part of. It
covers such broad, vast amounts of material and topics – interconnecting several
fields of science at once – not just your average chemistry course. It is truly awe-
inspiring, and confusing yet understandable at the same time. When I had first
decided to apply for this summer course, I really did not know what to expect;
however, it has surely blown my expectations to a new dimension in “spacetime”
and placed me in a foreign, newfound intriguing place for answers to long-
pondered questions.

Dylan agreed that he had already “felt awe once” in the course at the time of our initial interview, while discussing the various models of the universe:

When I was thinking about the cyclic universe, and the possibility that the big bang is only one of many, and that time has continued potentially infinitely, forever, before our big bang, and that for hundreds of billions of years there was probably life, and extremely complex civilizations, that definitely was pretty awe-inducing.

Throughout the course, each of the four participants continued to express similar emotions in their journal entries and in class dialogue, often while probing the philosophical or existential nature of the course content. In one particularly intense class following Sophie’s presentation on consciousness, several students engaged in a discussion about the distinction between mind and body (though Nicholas was notably quiet throughout this session):

**Olivia:** How do we define ourselves? Are we our brain? Are we our bodies? Are we just the thoughts in our brain?

**Dylan:** I consider myself to be just my brain and my thoughts, and I think it has to do with the way that I think about the rest of my body. So like, you know, I look at this hand, and I say, it’s my hand. I don’t say that it’s me. You know what I mean? The hand is something that I own and control, but it is not me. It’s just a thing that I have.

**Professor Holden:** So where’s the “me”?

**Dylan:** It’s a subset of everything you see here. I just don’t know what.

**Olivia:** Thoughts are based on opinions and give personality to a person. So if you lose a part of a person’s personality, they might be a different person altogether.

...  

**Sophie:** In the same way that we just questioned how we define life by the physical self or the mental self, you can also question whether people are dead when they’re brain dead. Think about when people have family members who are
in comas for extended amounts of time, but they keep the physical self going. And there are mental things occurring for that person while they’re in the coma, most of the time.

**Dylan:** Walt Disney is another good example, as he has been cryogenically frozen. Is he dead?

**Olivia:** This all turned into a big “I don’t know.”

**Sophie:** Yeah, it tends to do that.

**Olivia:** I think therefore I am?

**Sophie:** We definitely are…something. Probably. I mean, by human’s definition of something, we definitely are something.

In journal entries and conversations following this session, a number of students mentioned consciousness as a topic that had been particularly emotionally evocative for them.

At the end of the summer, Dylan, Nicholas, and Sophie all confirmed that they had experienced significant emotional investment in at least some aspects of the course. Though Dylan and Nicholas characterized their emotional response as mainly one of interest, Sophie felt confident that she had regularly experienced awe during the course. When asked if any element or concept was particularly meaningful to her, she responded:

Gosh. I mean, I felt like every day that someone presented, I kept just sitting there going **wow**, and **whoa**. A lot of the stuff about, like a lot of the information about stars definitely blew my mind, but also just the fact that we were able to connect the exact same principles of stars to humans was pretty cool. So like, I guess those two, what I may see as polar ends were actually so connected that it was like, that was the most impressive part to me, I think … the fact that we came after them, not at the same time as them. So it’s like a very confusing thing, but we are all made out of the same stuff, so it’s cool.

Overall, Chem 106 students’ reactions seem to suggest regular opportunities for emotional engagement with the existential implications of the content being covered. Though they were often hesitant to apply the word “awe,” it seems evident that all four
participants experienced a degree of intensity and depth to their emotional responses.

**Cross-Site Findings**

Having reported the findings for each instructional setting individually, I now turn to similarities and differences in themes across the two sites. In this section, I begin to draw connections to the contextual factors that may have contributed to differences that emerged, though I will further examine these factors in the Discussion section.

**Instructional context.** Though there were multiple differences between the instructional approaches used in DSI Junior Science and Chem 106 as well as some areas of overlap, one key distinction that emerged through my analysis of the pedagogy at each site was between process and content. At DSI, the instruction emphasized scientific *practices* by introducing students to historic discoveries and facilitating hands-on lab work, while at Chem 106, the instruction emphasized scientific *ideas* by asking students to understand and apply the concepts featured in assigned texts and class presentations.

As articulated on the program website and clarified in my interview with Lily, the goals of DSI Junior Science involved preparing students for future experiences in high school and college science courses, as well as developing a set of broader academic skills including effective study habits and critical thinking. At its most effective, the course pedagogy empowered students to envision themselves as current and future scientists, to see the application of skills like collaboration, critical thinking, and problem solving to other aspects of their lives, and to understand science as a promising avenue for solving important global problems. Where it faltered, the emphasis on process and the rigidity of the course schedule seemed to lead to cases of students going through the motions of
their labs and projects without achieving deep understanding or glossing over the broader implications of what they had learned.

As described by Professor Holden’s syllabus and our subsequent interview, the goals of Chem 106 involved introducing students to a wide-ranging set of scientific concepts, drawing connections between a cosmic perspective and the importance of environmental sustainability, and positioning science within a broader collection of disciplinary and cultural perspectives. At its most effective, the course pedagogy encouraged deep reflection about powerful and complex scientific ideas and helped students appreciate the value in an interdisciplinary approach to understanding the world. Where it faltered, the course’s broad scope and loose structure seemed to result in missed opportunities for students to use the assignments in targeted ways to advance their thinking; students also struggled to articulate the connections to sustainability beyond a general expression of discouragement or resignation.

Thus, comparing the pedagogical approaches of the two sites highlights several frequently encountered tensions in instructional design. Faced with limited time and resources, instructors must choose how to prioritize structure versus flexibility, breadth versus depth, and skills and practices versus conceptual knowledge. In the context of this study, the pedagogical decisions in each setting appear related to how students engaged with the instructional experiences and what they took away from each course as a result.

Students’ understanding of the relationship between the self and the scientific phenomena being studied. Students in DSI Junior Science primarily understood these relationships through a global lens. While students demonstrated an appreciation for how humans and other organisms interact within ecosystems, they were
less likely to situate these phenomena in specific local contexts or to acknowledge themselves as actors within the systems. In contrast, they did acknowledge themselves (though often using the first-person plural, such as in references to “our generation”) when discussing their relationship to the scientific enterprise.

Meanwhile, Chem 106 students often used a more personal lens to understand the relationships between humans and the global, or even cosmic, phenomena they were studying. Students frequently discussed the implications of the course content for themselves as individuals, including general existential reactions (e.g., *if the universe is so vast and unknowable, what does that mean for me?*) and more specific changes to their perspectives or behaviors (such as Dylan’s realization about the value of interdisciplinarity). However, they were less likely to discuss local or global implications, such as how the content might inform their thinking about the impact of humans on the environment.

It is highly plausible that this distinction was due in part to the different types of thinking invited by each course’s respective content, activities, and assignments. However, there are also important factors outside the realm of the course pedagogy that likely influenced this deviation in perspectives, a notion to which I will return in the Discussion section.

**The nature of students’ transformative engagement.** In DSI Junior Science, students were generally more likely to exhibit motivated use and experiential value than expansion of perception. The prevalence of motivated use is a reasonable outcome, given that the course placed a strong emphasis on enabling students to apply their learning to other academic contexts. However, student engagement was not simply pragmatic. As
indicated by the analysis of the sub-components of experiential value, DSI students also derived intrinsic meaning from what they were learning, though the evidence for this came largely from students’ use of language implying a personal reaction to the material, as opposed to explicit statements about how the content mattered to them.

Interestingly, the profile of engagement for Chem 106 students was flipped: while their levels of experiential value were similar to DSI students, they were generally more likely to exhibit expansion of perception than motivated use. Again, the prevalence of expansion of perception is logical in this context given the course’s goal of helping students open their eyes to new ways of understanding the universe through the course content. Perhaps unsurprisingly, then, instances of experiential value were skewed even more highly toward intrinsic meaning than they were at DSI.

As I will discuss further in the final section of this chapter, there are interesting implications for how students applied their developing understandings of connectedness that relates to these differing profiles of transformative engagement. In brief, while Chem 106 students were more likely to express the feelings characterized in the literature as “small self,” DSI students were more likely to identify prosocial or otherwise outward-facing implications.

**Elicitation of awe during the instructional experience.** Across both sites, students expressed some hesitation about the emotion of awe; many were not sure about the extent to which they had experienced it previously, and they did not frequently apply the term to their experiences during the summer courses. For the purposes of my analysis in this study, it was helpful to examine instances that resembled or approached awe, while acknowledging that the features might not directly match the definition in the
literature or might involve a lesser degree of intensity than the life-changing cases of awe often described by adults.

DSI students had a particularly hard time defining awe and talking about their experiences with it; they seemed to mostly understand awe as a synonym to other emotion words like shock, surprise, and amazement, rather as an independent emotion with a unique set of features. However, primarily from evidence in their DEJs and interview responses, it appears that DSI students did have some opportunities for strong deep emotional engagement during the course, especially with the notion that the biological systems they were studying in class were genuine phenomena occurring within their own bodies. The words they used suggested that these ideas evoked feelings in the realm of awe, including the synonymous emotions they had named like shock and amazement.

In general, Chem 106 students provided more complex and nuanced definitions of awe, which included elements from the definitions in the research literature and from the adult participants in Study 1 of this dissertation. From written work, class dialogue, and interview responses, all four participants demonstrated evidence that indicated they were experiencing awe or emotions resembling awe. These emotions often seemed to be elicited by concepts involving spatial and temporal scale; in particular, evidence of awe was frequently present in students’ reflections on the philosophical implications of the existence of these vast and complex systems.

These findings raise developmental questions to which I will return in the concluding chapter of this dissertation, particularly regarding the differences between the adolescent and adult participants in the two studies. Differences in students’
understanding of awe between the two sites, however, likely cannot be attributed solely to developmental stage; while Chem 106 students were older than DSI students overall, Olivia and Nicholas were only a single grade level above the DSI students. It is more plausible that the differences are the result of a number of complex factors, including the features of each instructional context as well as pre-existing differences between the two sets of students unrelated to their experiences with the course content or pedagogy.

Discussion

In this final section of the chapter, I begin by reiterating and synthesizing the major findings that resulted from the analysis within and across the two sites. Subsequently, I discuss several limitations inherent in the study design. Finally, I conclude by proposing a set of implications and directions for future research.

Summary of Key Takeaways

The findings of this study are especially notable when considered in the context of the theoretical framing that informed its design. This study was motivated – as was the dissertation writ large – by evidence put forth in the existing literature suggesting links between the emotion of awe, the sensation of small self, and an orientation toward the collective. The purpose of the present study was to explore these relationships as manifested in authentic learning experiences for adolescent science students.

As was the case in Study 1, participant responses to awe experiences were much more likely to occur at the level of shifts in perspective than changes in behavior. This may be in part due to a limitation of the study design, as I was rarely able to observe students outside the initial learning context. However, I observed very few instances in the instruction at either site where students were explicitly told how they could or should
apply the course content apart from deepening their understanding, nor were they prompted to reflect on this idea for themselves (aside from the journal prompts, which encouraged connection-making more generally but did not specifically facilitate connections related to awe experiences or the feeling of small self). In general, the findings suggest that students would benefit from further scaffolding to support transfer between the scientific phenomena addressed in class and specific implications for their own lives.

Beyond this overarching theme, there were also cross-site differences regarding the elicitation of feelings of small self and the corresponding prosocial inclinations as described in the literature. In general, Chem 106 students were highly inclined to reflect on the deep, existential questions provoked by the course content, and their descriptions of feeling simultaneously insignificant and connected to something larger are well aligned with the documented sensation of small self. However, these reflections were less likely to extend to humanity or the environment, despite the course goals of making connections to sustainability. Conversely, the language DSI students used throughout the summer was rarely reminiscent of small self, and the students did not tend to frame their understanding of the course content in terms of its relation to themselves as individuals, yet they were generally more inclined to discuss implications for public health and sustainability.

A combination of factors likely contributed to these divergent outcomes. First, it is safe to assume that the specific content covered in each program elicited different thoughts and reactions from students. The genetics curriculum in DSI Junior Science, with its emphasis on new and anticipated future advances in biotechnology, logically
evokes reflections about large-scale implications for global health. Meanwhile, it is reasonable that in Chem 106, a course that covered the history of the universe from its origins to the present day and concluded with a deep dive into the nature of consciousness, students would be inspired to consider existential questions about their own identity and significance. Moreover, the pedagogical approach and specific learning objectives of each instructor likely played a key role in how students engaged with the material. At DSI, Lily regularly provided specific examples of how modern science can offer pragmatic solutions to real-world problems, while in Chem 106, Professor Holden’s attention to the interaction between science and sustainability often took a more philosophical stance.

While the nature of instruction at each site was surely influential, it is also imperative to note that the two programs attracted two groups of students who were systematically different from the outset. I will return to these differences and the questions they raise about opportunity and equity in the final subsection on implications.

**Limitations**

Several key limitations of this study are worth acknowledging. These include issues raised by the sampling strategy and methods of data collection as well as the interpretive biases I bring to the analysis.

First, my site selection was informed by publicly available information about existing summer programs and the willingness of site administrators and instructors to welcome me as a participant observer. As the two sites chosen for the study varied significantly in multiple dimensions (demographics of participants, content area, instructional style, etc.), it was challenging to isolate any single dimension as a
contributor to impacts on student thinking, and it may well be the case that the impacts documented in the data arose from the interaction between these factors. Moreover, I found once I began data collection that the stated instructional goals for the sites as advertised in public program materials were sometimes misaligned with the goals conceived of and enacted by the instructors; this was especially true for DSI. In future research, I hope to select sites with which I have greater familiarity prior to beginning data collection.

Additionally, my sources of data came primarily from the initial instructional contexts (class sessions and student assignments). The interviews provided occasional opportunities to speak to students outside of class, but still occurred within the six weeks of the programs. This structure made it difficult to investigate the extent to which students saw connections to their lives beyond the course settings. It would be useful to design a study that includes the opportunity to re-contact students weeks or months after instruction has ended so that they can report on additional opportunities that they have identified to apply their learning.

One aspect that was largely missing from the data I collected at both sites was the nature of the relationships between the students and instructors. Presumably, this is due in part to the short duration of the programs, which may have made it difficult for deep relationships to form, and also due to limitations in what I was able to observe. Of course, it is well established in the literature that the development of strong teacher-student relationships plays a key role in cultivating student engagement and motivation (e.g., Pianta, Hamre, & Stuhlman, 2003; Roorda, Koomen, Spilt, & Oort, 2011), and the nature of these relationships at the two sites in this study likely impacted the extent to which
students were able to experience transformative engagement with the course content. This facet of the instructional context warrants further attention in future research.

Finally, as was the case in Study 1, my familiarity with the existing literature and my prior experiences as a science learner and teacher surely informed the lens I brought to the design and analysis of this study. My choice to employ additional researchers in a collaborative coding process was an effort to increase the validity of my findings. Moreover, designing this study to span two diverse instructional contexts provided a means of surfacing themes that may not have been apparent had I conducted the research within a single setting.

Implications and Directions for Future Research

**Implications for pedagogy.** As has been repeatedly discussed, the effects of awe and small self that have been demonstrated in experimental research are harder to observe in settings outside the lab, where the distance between the stimulus and the opportunities for application is typically farther apart in space and time. In the context of this study, it is not clear whether the lack of evidence for transfer, especially with regards to behavior, resulted because it was simply not occurring, or at least in part because the methodology could not capture it as it occurred outside of the class setting. Within the classroom setting, instructional designers and educators should develop strategies to help students more successfully identify opportunities for transfer. Additionally, better methods for documenting whether and how students are applying their understanding beyond the scope of the initial learning context would be useful both as an assessment tool for educators and a measurement tool for researchers.
Additionally, the kinds of data I collected in this study gave me insights into student thinking that in some cases went beyond the information the instructors could access. For instance, the data enabled me to identify moments where awe and other strong emotions were elicited and to investigate how students reacted to and made sense of that emotionally evocative instruction. Information of this nature would be useful to educators who are attempting to design instruction to evoke awe. Teachers may wish to consider using journals, one-on-one student conversations, or other means of collecting this sort of data from their own students in order to inform their practice.

**Implications for equity.** Finally, it is important to attend to the systematic differences in demographics between the two programs and to consider how these differences may have interacted with student learning and the outcomes observed in this study. As discussed previously, Chem 106 students were, on average, 1-2 years older than the students at DSI. It is possible that students’ developmental stage contributed to the level of nuance with which they were able to understand and discuss the concept of awe and other complex topics relevant to this study.

Perhaps more important than this age difference, however, was the relative privilege held by students enrolled at each program. My study protocol did not enable me to collect demographic information about individual participants, but it is possible to make inferences based on the features of the programs themselves. As noted above in the descriptions of each site, DSI is a free three-year program for which the eligibility requirements include low income and local residence; the majority of participants are students of color and many are first-generation Americans. Meanwhile, the Gifford University program that hosts Chem 106 can cost over $10,000 for a single summer; it
draws students from all over the country as well as a significant number of international students, many from Asia. Based on this information and the personal anecdotes students shared in their interviews, it is safe to assume that most, if not all, of the students in Chem 106 came from positions of significantly higher socioeconomic status than the students at DSI.

New insights and questions surface when the observed differences between students at the two sites are considered in light of the average economic and cultural capital held by each group. How should we interpret the finding, for instance, that Chem 106 students’ reflections were typically focused on the implications of the course content for their own purpose and significance, while DSI students’ takeaways were generally removed from the self? What to make of the fact that students at DSI were attracted to biotechnology as a promising opportunity for their future professions, while the students in Chem 106 (especially the college students) were inclined to view science as a hobby to pursue – or even, as Sophie worried, a lens for “thinking about life as opposed to living it”?

It is worth considering the role that economic stability and societal privilege play in empowering individuals to take a step back from daily concerns and reflect on their place in the universe. In the concluding chapter of his popular book *Astrophysics for People in a Hurry*, astrophysicist and science communicator Neil deGrasse Tyson comments on the reality that not all people are equally free to adopt a cosmic perspective:

> [W]ho gets to think that way? Who gets to celebrate this cosmic view of life? Not the migrant farmworker. Not the sweatshop worker. Certainly not the homeless person rummaging through the trash for food. You need the luxury of time not spent on mere survival. You need to live in a nation whose government values the search to understand humanity’s place in the universe. You need a society in
which intellectual pursuit can take you to the frontiers of discovery… (Tyson, 2017, p. 194)

In a broader sense, of course, all of the participants in this study are among the world’s most fortunate. Each of them had the time, resources, and intellectual capacities to spend six weeks pursuing optional education at an elite academic institution. Yet comparatively, there is no question that outside the campuses of Darby and Gifford Universities, these two groups of students have had substantively different life experiences – and, presumably, different expectations and goals for how science can and should factor into their future lives as adults. Any study investigating the impact of transformative awe experiences must acknowledge these questions about who has the luxury to fully pursue them.
Section 3

Chapter 5 | Overall Conclusions

Taken together, the two studies presented here could be viewed as telling a developmental story. The age range of participants in this dissertation spanned nearly six decades, from 16 to 74 years old. At the youngest end of the spectrum, the adolescent participants in Study 2 represent the perspectives of novice science learners who may be weighing the role that science will play in their personal and professional lives moving forward. Meanwhile, the participants in Study 1 represent the perspectives of a diverse range of professional scientists, some who are just getting started and others who are nearing the end of their careers. From a participant like Richard (Study 1), one can begin to piece together how a lifetime of cumulative experiences of awe in science, starting as a young scholar, have contributed to his current view of science as a profession and of the world more broadly. Likewise, one might wonder how experiences of awe in science will continue to shape the worldviews of a student like Alisha or Nicholas (Study 2) decades down the road.

What conclusions can be drawn from this dissertation about how best to support student learning? In truth, the specific pedagogical implications likely depend on the nature of our goals as educators, as well as the goals held by the students themselves. In some cases, we may be seeking to encourage students to pursue and sustain a successful career in the sciences. In other instances, we may wish to help learners understand how science can expand their appreciation for the natural world and inform their perspectives and actions as global citizens, even if they never take another science class. Or perhaps we want students to see themselves as members of a scientific community, whether they
become expert practitioners or simply well-informed consumers of science. In this final chapter, I will revisit three key findings from the dissertation and consider what they might mean for these different pedagogical goals before concluding with several recommendations for future research.

**Key Findings**

**The Relationship between Awe and Learning or Accommodation**

The findings from both dissertation studies reveal a relationship between awe and the process of learning or realization that is in line with existing theoretical and empirical research, including research positing a specific relationship between awe and science learning (Gottlieb, Keltner, & Lombrozo, 2018; McPhetres, 2019; Valdesolo, Shtulman, & Baron, 2017). The dissertation data suggest that the primary stimuli that elicit this sense of awe change over time; this change is likely due to development, an increase in expertise or context, or some combination of these factors. For younger learners, awe is frequently derived from a new conceptual understanding that they have developed in a science class or through some other secondhand source. This was apparent for the adolescents in Study 2 but also in the recollections by participants in Study 1 of their early experiences of awe in science. In these examples, participants described or demonstrated a sense of awe elicited by grasping an idea or phenomenon that had previously not been clear or intuitive to them. Meanwhile, the more recent awe experiences described by participants in Study 1 were largely in the context of their own direct involvement in scientific inquiry. In these cases, the awe was often elicited by the experience of being the person to uncover a new piece of knowledge about the universe, no matter how small. While such experiences involve encountering new information,
they may or may not necessitate accommodation depending on the nature of the
discovery.

It is worth briefly revisiting here the debate in the literature referenced in Chapter 2 regarding the extent to which awe actually does result in accommodation. As argued by authors like Schneider (2017) and Schinkel (2017), awe involves a state of reverence or humility in the face of something knowable, whereas the process of accommodation is better classified as occurring through an emotion like wonder. Whether this is a matter of semantics or a true substantive debate is not necessarily clear; regardless, it is useful to note that the participants in this dissertation did see accommodation as possible within the context of awe, especially as demonstrated through the definitions provided by the scientists in Study 1. It is also notable that many participants in Study 1 described the temporary sense of disequilibrium that precedes accommodation as a positive, or at least welcome, state of affairs. This seems in line with prior findings that a greater tendency for dispositional awe is associated with higher levels of open-mindedness more generally, as well as with a greater appreciation more specifically for the idea that the scientific process involves abandoning prior models in light of new evidence (Gottlieb, Keltner, & Lombrozo, 2018; Shiota, Keltner, & John, 2006; Silvia, Fayn, Nusbaum, & Beaty, 2015). One implication of this finding is that there is value in striving to increase learners’ sense of comfort with uncertainty, which may open them to more opportunities to experience awe as well as encourage them to consider new scientific ideas that are initially challenging or counterintuitive. This is likely a worthwhile endeavor whether the learner is considering a career in science or not.
**Awe as a Source of Motivation**

A second key finding from the dissertation was the relationship between awe and motivation. This finding was most present in Study 1 and was connected to opportunities for authentic inquiry; the “fuel” that scientists described was generated by active participation in the process of scientific discovery. It is notable that the theme of motivation was largely absent in Study 2, where participants’ experiences with science primarily involved learning through secondhand sources (e.g., textbooks and lectures) and through the replication of experiments where the results were already known. Interestingly, some of the participants in Study 2 may have intuitively had a sense that there was further awe to be derived from genuine scientific practice. Fatima expressed an interest in conducting her own independent research in the future, even if she was not yet sure what the subject of focus might be, and Nicholas explicitly predicted that he would be unlikely to feel a sense of awe in science until he made a discovery of his own.

For professional scientists and those seeking to enter the field, the findings suggest implications regarding the institutional constraints that limit opportunities for awe, especially given the testimony of participants like Francesca (Study 1), who left research because moments of awe were so hard to come by in the face of funding and publication pressures. Interestingly, these pressures are somewhat parallel to the factors that limit students’ abilities to participate in genuine scientific discovery. Institutional constraints like standards, resources, and access to sufficient professional development all prevent teachers and curriculum developers from designing opportunities for authentic inquiry at the K-12, and even postsecondary, levels of science education.
The Complex Relationship between Awe, Small Self, and Prosociality

The promise of awe’s role in facilitating prosocial inclinations and behaviors was one of the primary factors that motivated this work. However, evidence of such a relationship was fairly weak in both dissertation studies, especially in relation to other more salient findings. In the section below on directions for future research, I propose some methodological approaches that might more effectively test for the presence of this mechanism. Here, I wish to suggest that the existing findings point to a need for more explicit opportunities and cues for transfer, for novice learners and expert scientists alike.

As found in Study 1, scientists did appreciate their positionality in relationship to the vast and complex natural systems they were studying, though this theme often did not emerge without explicit prompting from the interview questions or video clip. Notably, even for those scientists who acknowledged this sense of small self, few went on to describe the implications beyond a general sense of awareness or appreciation. If participants did experience an increase in their altruistic inclinations and tendencies, it was generally not at a level that had reached their conscious perception.

In Study 2, Lily and Professor Holden both expressed the hope that their curricula would help students think critically about their roles and responsibilities as participants in natural systems, and at least some of the students at each site did identify a relationship between a sense of connectedness and a general need for action. For instance, multiple DSI students noted the complexity of phenomena like the dairy industry or the spread of the Wolbachia parasite. These students said it was important to attend to how human behavior within these contexts affects the larger ecosystem, but they did not name specific actions that they could take as individuals. Meanwhile, the students in Chem 106
reflected on the dire nature of anthropogenic climate change, but similarly did not extend these reflections to their personal behaviors.

These findings suggest that the messaging about human involvement in natural systems is likely too subtle at every level of science education to prompt regular reflection on the role of individuals – or, to the extent that these ideas exist in the curriculum, they may not be presented in ways that elicit feelings of awe or small self. If the findings from laboratory studies like those conducted by Piff et al. (2015) are to be believed, science educators should find ways to capitalize on moments of awe and use those as opportunities to explicitly discuss the implications for human behavior. In other words, we should be reminding students about the ways that they can contribute productively to natural systems at the moment when they are most likely to feel a deep, emotional sense of care and concern for those systems. This is a goal that seems especially worthwhile for all learners, whether or not they intend to pursue careers in science.

However, while feelings of small self as typically described in the literature were largely absent for the participants in these studies, there was another context in which this phenomenon was quite present. In Study 1, participants overwhelmingly described a deep awareness of their membership within a vast community of scientists spanning geography and time, a realization that in and of itself seemed to generate awe in quite a few individuals. A number of the adolescents in Study 2 also demonstrated a modified version of this feeling. At DSI, students were explicitly encouraged to visualize themselves as future scientists, and some of them appeared to try on that persona in their journals by identifying with the renowned scientists in their textbook and discussing the skills that
would benefit them in their own careers. For students in Chem 106, science was presented as a way of knowing – students were provided with the opportunity to think scientifically and invited to discover a sense of awe in the experience of unlocking mysteries of the universe, even if they were not planning to pursue science professionally.

The notion of connectedness to a scientific community, or even to the scientific enterprise writ large, seems valuable for both professional practitioners and more casual consumers of science. It offers the opportunity to expand one’s worldview and enables the adoption of an identity that welcomes all humans involved in the endeavor of trying to understand the universe. As noted by participants in both studies, this mindset facilitated a sense of communion with other scientists not just in the present but in the past and future as well. When taken to its logical conclusion, the idea of membership in a scientific community can empower individuals to view themselves as part of a legacy that extends well beyond their individual careers or lifespans. For educators who worry that the feeling of small self might leave students stricken with an overwhelming and paralyzing sense of insignificance, presenting this more positive outlook on the opportunity to contribute to the continued existence of humanity could be a valuable antidote.

**Directions for Future Research**

The findings from this dissertation reveal several new directions for future investigation. Additional lines of inquiry may serve to further bridge the gap between the existing body of experimental research that comes largely from cognitive psychology and studies like the ones in this dissertation that are informed by educational research and
qualitative methodologies. In particular, I propose that future research should involve 1) the use of mixed methods, 2) additional strategies to more effectively probe the nature of the developmental trajectory, and 3) investigation of other populations that would complement the present focus on professional scientists.

**Using Mixed Methods Approaches**

As discussed, some of the findings from this dissertation provide further confirmation for conclusions from prior theoretical and empirical work on awe and science; in other cases, the dissertation findings conflict with existing evidence, especially about the relationship between awe, small self and the effects on behavior. In future research, combining qualitative and quantitative methods could be a valuable approach to investigate these conflicting findings. For instance, one strategy would involve incorporating some of the measures used in prior laboratory research to examine the effects of more organic learning experiences; such an approach could help determine whether the effects found in studies like those found by Piff et al. (2015) are in fact present outside the lab and are simply harder to capture with interviews and observational methods. Conversely, a metacognitive task could be added to lab procedures that asks participants to reflect on the perceived effects of the awe-inducing stimuli. Including follow-up components after a time lapse (e.g., contacting participants one week after the initial protocol) would also help determine the extent to which any measured effects from the stimulus linger, either consciously or subconsciously, for participants.

**Exploring the Interaction between Development and Metacognition**

This dissertation illuminated developmental differences between how the adults in Study 1 and the adolescents in Study 2 described their experiences of awe, as well as the
potential for more nuanced developmental differences that may have existed between the students in the two Study 2 sites. One remaining question is the extent to which these apparent differences are a product of an individual’s capacity to experience awe versus one’s ability to reflect on and articulate the nature of those experiences. To further examine this distinction, future research should employ methods that provide younger participants with tools to scaffold the process of identifying and describing their experiences, such as using other terms for the emotion that they may be more familiar with, offering examples, and incorporating structures like targeted journal prompts to invite reflection (all strategies that would presumably help adult participants, as well). If these strategies reduce the observed gap between adult and youth responses, it would suggest that the developmental differences are more related to metacognitive abilities. If not, it is more likely the case that the differences are in the nature of the awe experiences themselves and how they are perceived by individuals at different developmental stages.

**Juxtaposing Science with Other Disciplines**

The findings from this dissertation also revealed key features of awe in the context of science that were present to different degrees than the features described in more domain general characterizations of awe in the literature. One way to extend this research would be to conduct similar studies using a parallel methodology to Study 1 to investigate the features of awe as they manifest in other academic disciplines. It would be especially valuable to select a discipline (e.g., history or literature) that differs significantly from science in its methods of inquiry. Such a study might probe how practitioners describe the nature and impact of awe experiences in the context of their discipline. In particular, one might investigate whether similar themes emerge regarding
membership to a disciplinary community, as well as the extent to which these
professionals perceive a relationship between awe and motivation. In addition to
broadening our understanding of awe more generally, looking for features that are absent
or less common in other disciplines could enable researchers to further pinpoint the
features that are specific to awe experiences in science contexts.

**Investigating the Experiences of Science “Hobbyists”**

Finally, another population that might warrant further investigation is amateur
science hobbyists or enthusiasts – that is, adults who have not taken a science course
since high school or college but who still regularly enjoy activities like reading science
news articles, visiting science museums, and so on. How might these individuals
experience moments of awe in the context of science? There is value in studying adult
science hobbyists because any observed differences with professional scientists would
not be due to developmental capacity; rather, the key differences between the two groups
would be in their level of expertise and the extent to which they are actively participating
in scientific inquiry versus learning about science secondhand. Presumably, science
hobbyists’ examples of awe would more closely resemble those of the younger learners
in this dissertation – i.e., more commonly derived from conceptual understanding – since
they are not directly involved in the process of discovery; this hypothesis is worthy of
empirical investigation. Additional questions to explore include the extent to which
science hobbyists see themselves as members of the scientific community and whether
awe is a motivating factor in their pursuit of science activities.
Final Thoughts

As I near the end of this work (or, at least, this phase of the work), the questions of equity and opportunity raised in Chapter 4 linger in my mind. Some of the effects of experiencing awe in the context of science suggested by this dissertation have the potential to yield significant benefits for all individuals, not just those who choose science as a career path. Most notably, there is a sense of comfort to be gained from envisioning oneself as being a part of the great human enterprise of discovery, and it is unjust that this feeling should only be available to those who have the luxury of time and resources to pursue it.

Throughout this dissertation I have noted that the study of awe has only been an object of focus in the field of psychology for the past two decades, and research at the intersection of awe and science is even newer. It is not the case, of course, that people have only just begun to notice this relationship. I wish to conclude with quotations from three astronomers, whose lives span nearly two millennia, that I believe capture the spirit of this dissertation’s findings and their implications.

I know that I am mortal by nature and ephemeral, but when I trace at my pleasure the windings to and fro of the heavenly bodies, I no longer touch earth with my feet. I stand in the presence of Zeus himself and take my fill of ambrosia.
– Ptolemy, c. 150 AD\textsuperscript{10}

In its encounter with Nature, science invariably elicits a sense of reverence and awe. The very act of understanding is a celebration of joining, merging, even if on a very modest scale, with the magnificence of the Cosmos. And the cumulative worldwide build-up of knowledge over time converts science into something only a little short of a trans-national, trans-generational meta-mind.
– Carl Sagan, 1995\textsuperscript{11}

\textsuperscript{10} As cited in Gingerich (1993), p. 55.
How I deal with the world today, especially with the politics of the world, is I’ve got to believe that all this short-term stuff doesn’t matter so much. It’s got to be the longer-term stuff that matters, right? We’re not trying to lower our taxes in the next five years, we’re trying to survive for ten thousand years so we can find some aliens. And maybe that’s leaked into my philosophy of the world, of how we should be thinking about, as a society, what are we trying to do here? I think that’s definitely changed my perspective on things – on how unimportant we are, maybe. And so if we want to be important, or if we want to make an impact, what’s important to humanity is its continued existence, rather than the individual.

– Henry, Study 1 participant, 2018
Appendix A: Study 1 Interview Protocol

I’d like to start by learning a little about the path that led you to become a scientist. What drew you to this profession?

Were there any specific experiences or moments that stand out for you when you think about your motivation for entering this field? If the participant does not mention any experiences from childhood: At what age do you think you first felt this way about science? Do you recall any experiences from childhood that connect to your current interest in science?

What do you think of when you hear the word awe? How would you define this word?

Have you ever experienced awe in the context of your field of expertise? If so, can you tell me about that experience?

Did this experience change your thinking or perspective in any way? If so, how?

Did this experience influence your behavior in any way – either in your professional context or in your daily life? If so, how?

In thinking about this impact of the awe experience you’ve described, would you characterize it as short-lived, or long-lasting? If short-lived: Why do you think the impact dissipated over time? If long-lasting: Why do you think the impact has persisted for you?

Can you recall any other awe experiences in the context of science? If so, can you tell me about a second moment that you remember? [As appropriate, use the same follow-up probes as above]

Would you say that the experiences of awe that you described are isolated or unusual incidents, or is the feeling of awe something you experience with some regularity through your work?

Some people have described awe as an experience of feeling part of something larger than yourself. Does that resonate with you, or is that not how you experience awe? Can you say more about why it does (or doesn’t) resonate?

Are you familiar with the concept of the overview effect? [Either way, show short explanatory video (timestamp 0:00-2:00 and 4:30-6:30).]

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12 These clips come from Overview, “a short film documenting astronauts’ life-changing stories of seeing the Earth from the outside – a perspective-altering experience often described as the Overview Effect. . . . Overview is a short film that explores this phenomenon through interviews with five astronauts who have experienced the Overview Effect. The film also features insights from commentators and thinkers on the wider implications and importance of this understanding for society, and our relationship to the environment.” (Description taken from video link: https://vimeo.com/55073825)
What are your reactions to this video?

A researcher has suggested that there might be other “overview-effect-like” phenomena that exist in other domains of science – in other words, experiences that lead to a shift in perspective and a possible accompanying shift in behavior. Based on either your own personal experiences, or just your hypothesizing, what do you think about this?

If you were trying to use concepts or experiences from your own area of expertise to generate this type of effect in someone who is not a scientist, how might you do it? What would you expect the shift in perspective to look like? What would you expect the shift in behavior to look like?

Has this interview raised any other thoughts or ideas that you’d like to share? Do you have any questions for me?
### Appendix B: Study 1 Partial Codebook

<table>
<thead>
<tr>
<th>Code Family</th>
<th>Code</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definitions of Awe</td>
<td>Learning/realizing something new</td>
<td>Defines awe as an emotion elicited by exposure to new information or the development of a new understanding</td>
<td>“It’s like, what you learned in one class is actually a bigger part of what you learned in another class and you have this kind of a-ha moment and you realize that this is true … Once everything really connects, you get this sense of awe.”</td>
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<tr>
<td></td>
<td>Sense of wonder</td>
<td>Defines awe as comparable to other similar emotions like wonder, amazement, or disbelief (often through the use of synonyms)</td>
<td>“Something to be amazed by, fascinated by, maybe inspired by.”</td>
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<td></td>
<td>Presence</td>
<td>Defines awe as an experience where one is fully captivated or has a heightened sense of awareness</td>
<td>“In your mind you have this constant narrative of what’s going on … and then something subconscious kicks in, and all of your senses are engaged, and you’re trying to really absorb what you’re seeing or hearing … and in a way, it’s sort of breathtaking.”</td>
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<td></td>
<td>Sense of scale</td>
<td>Defines awe as being elicited by the perception of something at a significantly different scale than the self (usually larger, but sometimes smaller)</td>
<td>“It’s an emotion that you get when you feel really small, when you feel like forces of nature are overwhelming. When you’re sort of like a fly in a hurricane.”</td>
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<td></td>
<td>Equation with science</td>
<td>Defines awe as being an integral part of the scientific process, often in a way that suggests that awe and science are inextricably linked</td>
<td>“You reach this moment, you have awe, and then you go, ‘Well, how do I comprehend this, and how do I understand it, and can I get beyond it?’ Maybe that’s how I see it. It’s the first step of our scientific process.”</td>
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<td></td>
<td>Positive or negative valence</td>
<td>Defines awe as having inherent positive or negative qualities</td>
<td>“It’s something that’s unusual but it makes you happy. Like, it gives you feelings of curiosity, rather than disgust … because something unusual or new could actually make you feel really averse, and I think instead awe has a positive aspect to it.”</td>
</tr>
<tr>
<td>Identified Elicitors of Awe</td>
<td>Awe elicited by the process of one’s own scientific inquiry (e.g., collecting data, getting results, etc.)</td>
<td>“For me, I just think in that moment where your experiment works perfectly or you get the results you were looking for or that were totally unexpected and you’re just like, this is awesome, this is going to be huge.”</td>
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<tr>
<td>Seeing with one’s own eyes</td>
<td>Awe elicited by the experience of directly observing a phenomenon</td>
<td>“Seeing really big mountains for the first time since I had learned about geology. So South America’s kind of special because it’s one of these active margins, where you have two plates coming together. One goes under the other one, and that’s what drives the volcanism. And I think, you know, when I learned about that in class, four years before I ever actually saw it, it really made an impression on me, and I got to see the actual landscape, it was really, really impressive.”</td>
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<tr>
<td>Conceptual understanding</td>
<td>Awe elicited by a scientific fact or concept</td>
<td>“The first time I had really, really studied the genome, I remember learning how complex and how perfect it was, and being just floored by it. I wanted to tell everybody about it, like, ‘You guys don’t understand how crazy the genome is!’”</td>
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<tr>
<td>Fieldwork</td>
<td>Awe elicited by the experience of conducting research in the natural world</td>
<td>“I actually remember getting off the plane and then on the sea ice, and just being completely surrounded by ice and snow and mountains, everywhere you look. That was definitely a moment of awe for me, just incredible beauty.”</td>
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<tr>
<td>Type of Awe</td>
<td>Description</td>
<td>Example</td>
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<tr>
<td>Sense of scale</td>
<td>Awe elicited by the relative vastness or smallness of a phenomenon (in size, time, quantity, etc.)</td>
<td>“It’s certainly a broadening perspective in terms of me seeing, either from the Grand Canyon, that this world is so big that it has these enormous walls of rock and there’s a whole lot more underneath, to the small, there’s this handful of soil there with thousands of bacteria, most of which are new to science. So I think it certainly widens my perspective on like the scales at which the world can operate.”</td>
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<td>Effort/sense of accomplishment</td>
<td>Awe elicited by one’s personal effort</td>
<td>“Part of it, I think, is almost a sense of, power, slash, I did this. If I was the one to write the proposal and get the time and get the funding to get on the airplane to go and drive there and drive up the mountain, but then also be the one controlling everything, I think that adds to it.”</td>
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<tr>
<td>Feat of science/engineering</td>
<td>Awe elicited by a scientific accomplishment (not necessarily one’s own)</td>
<td>“This is something I feel every time I take an airplane and the airplane takes off. Humankind did something amazing.”</td>
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<tr>
<td>Membership in the scientific community</td>
<td>Awe elicited by the sense of belonging within a scientific community (either one’s contemporaneous peers or over time)</td>
<td>“Science obviously has a long history, everyone who came before you, down to Euler, and Lagrange, and everyone who came before, like hundreds of years ago, and they saw the same thing, and they thought it was mesmerizing what they saw. And so you kind of feel yourself in this long legacy of scientists going back.”</td>
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<tr>
<td>Role of context or expertise</td>
<td>Reference to the ways that prior knowledge or experience shapes one’s current experience of awe</td>
<td>“There is kind of an appreciation, like you have had to have gone through the experience of something in order to appreciate, to get that sense of awe when you learn something new, even if you didn’t necessarily work for it.”</td>
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</tr>
<tr>
<td>Identified Impact of Awe Experiences</td>
<td>Motivation for future work</td>
<td>Awe as a driver for continued pursuit of science</td>
<td>“Those moments are more like lowkey fuel, I would say. Like, this is why I do what I do, right? This is why I find my work worthwhile, because I think this stuff is cool, and I feel this sense of awe about it.”</td>
</tr>
<tr>
<td>Change in perspective</td>
<td>Awe as the trigger for a new understanding or perspective shift</td>
<td>“You understand how if you go down to scales small enough, you understand how physics and chemistry, the line between them gets blurred, and even though I’m a chemist, I have to understand these difficult physics concepts. So that was a really awe-inspiring moment for me, and I sort of understood fundamentally how chemistry fits into the physical world.”</td>
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<tr>
<td>“Small self”</td>
<td>Awe as triggering a reflection on one’s positionality in relation to something greater than the self</td>
<td>“It’s almost humbling, so to say, this kind of feeling … that we are this little speck of dust in this greater atmosphere.”</td>
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<tr>
<td>Impact on one’s broader life experience, perspective or behavior</td>
<td>Awe as having a cognitive, affective, or behavioral impact outside of the context of science</td>
<td>“I would definitely say it boosts my mood… You just have a smile on your face and that can just be good. You could have a more optimistic view on things.”</td>
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</table>
Appendix C: Cluster Analysis of Scientists’ Awe Examples

After coding for the features of participants’ awe experiences, I used a mixed methods approach to investigate the extent to which participants fell into groups or clusters based on their patterns of responses. To conduct this analysis, I first created a matrix in which the rows represented the participants and the columns represented 23 prevalent features of awe that appeared in my codebook, and used a binary coding scheme (i.e., 0 or 1) to mark the presence or absence of each feature for a given participant. With the tools available in XLSTAT (XLSTAT, 2017), a statistical program designed for use in Microsoft Excel, I then used agglomerative hierarchical clustering to identify three clusters of participants (see Figure A1).

Figure A1. Dendrogram summarizing the hierarchical relationship between participants based on the features referenced in their examples of awe.
This analysis enabled me to produce Figure A2, which displays the features of awe by how prevalent they were in the responses for each group of participants. Looking at the righthand column of this table (responses referenced by 76-100% of respondents in a group) provides a glimpse into the most prevalent features of awe mentioned for each group of participants. For instance, participants in Group 1 were more likely than other participants to describe awe as a source of motivation, while participants in Group 3 were uniquely struck by feats of science and engineering.

In examining the makeup of participants in each group, no readily discernable patterns emerge to indicate that these different response patterns are associated with demographic traits. Each group is diverse in age/experience level, gender, and scientific discipline. This suggests that participants’ experiences with awe in science are likely quite personal and idiosyncratic.
<table>
<thead>
<tr>
<th>Groups</th>
<th>Percentage of Respondents in Group who Referenced a Given Feature of Awe</th>
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<td>0-25%</td>
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<td>Group 1: Ana, Andrew, Ben, Beth, Clara, Eric, Eva, Gino, Henry, Isabelle, Kyle, Luke, Pearl, Richard, Sarah, Urvesh, Vivien, Vonne</td>
<td>Collecting Data</td>
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<td>Group 2: Chris, Dawn, Ian, Mark, Nadia, Owen, Quinn, Ted, Will</td>
<td>Getting Results</td>
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<td>Group 3: David, Francesca, James</td>
<td>Beyond Comprehension</td>
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Figure A2. Participants clustered by patterns of responses in their descriptions of experiences of awe in science.
Appendix D: Study 2 Field Note Guide

The following list of prompts guided my field notes and analytic memos for Study 2. The prompts move along a spectrum from observational to interpretive/reflexive.

• What instructional activities did I observe today? What were the primary features of the instructional design?

• What logistical details about student engagement did I observe? (For instance, number of students present, individual vs. group work, types of participation [writing, discussing, hands-on], etc.)

• What sorts of visible responses to the instruction did I observe? (For instance, facial expressions, verbal reactions, movement, etc.)

• Did I observe any explicit or implicit references to the concept of connectedness? If so, how did these references manifest? Which participants made them?

• Was anything notable or surprising about the instructional activities I observed today?

• What is my interpretation of how students engaged with the instruction? (For instance, how would I characterize their emotional states based on what I observed? How focused/invested in the experience did they seem?)

• Did I see any evidence that students were experiencing “small self”? If so, what did I observe that suggests this? Which students do I think experienced this?

• Did I see any evidence that students were experiencing awe? If so, what did I observe that suggests this? Which students do I think experienced this?

• How does this observation compare with prior observations? What notable differences have I observed? What trends are emerging?

• Do I notice myself forming any opinions of the participants or their behaviors? Do I see evidence of my own biases or beliefs interacting with my interpretations?

• What do I want to follow up on with the instructor?

• What do I want to follow up on with individual students?

• Is there anything I want to do differently at my next observation?
Appendix E: Study 2 Student Interview Protocol (Preliminary Interview)

Part 1: General Background Information
I’d like to begin by getting a general sense of your feelings toward science. Is science a subject you like, or not so much? Is science a subject you feel like you are good at?

Can you tell me what you know about the unit/program you have just begun? What is about? What kinds of things are you expecting to learn? What kinds of things are you expecting to do?

Was there anything you particularly liked about today’s class/session? What did you like about that experience? What did it make you think about?

Was there anything you didn’t like so much about today’s class/session? What didn’t you like about that experience? What did it make you think about?

Part 2: Connectedness
I’d like to get your perspective on a few concepts that are of interest to me in my research. The first is “connectedness.” Can you tell me what comes to mind when you hear that word? How would you define it? What does a sense of connectedness feel like?

Can you tell me about a time when you experienced a sense of connectedness? What did you feel connected to? What impact did this experience have on you? Are there ways that feeling a sense of connectedness shapes how you understand the world? Are there ways that feeling a sense of connectedness shapes how you act in the world?

Do you see the concept of connectedness as being present within the subject of science? If so, can you give me an example?

Part 3: Awe and Small Self
Another concept I’d like to get your perspective on is the emotion of awe. Can you tell me how you would define this word? Can you give me an example of a time when you have felt awe?

Have you ever experienced awe during a time when you were learning science, either in school or out of school? If so, can you give me an example?

Some people have described awe as an experience of feeling part of something larger than yourself. Does that make sense to you, or is that not how you experience awe? Can you say more about why it does or doesn’t make sense?

Part 4: Wrap-Up
Is there anything else that this conversation has made you think of that you’d like to share? Do you have any questions for me?
# Appendix F: Study 2 Transformative Engagement Codebook

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<tr>
<th>Component of Transformative Engagement</th>
<th>Definition (as quoted from Pugh et al., 2017)</th>
<th>Example from Data</th>
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<td>Motivated Use</td>
<td>“Refers to the application of school content in out-of-school contexts where application is not required”</td>
<td>“I am picturing [a television episode] in which one character says that a type of shoe polish is ‘carcinogenic.’ I remember watching this episode and being confused because I had no idea what that meant. Now, I understand that it has to do with the causing of cancer. This makes a lot of sense because the characters did not want the shoe polish near them after finding out that it was carcinogenic. I am glad that now I know this word so that I can better understand things like this or engage in conversations about it.”</td>
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<td>Expansion of Perception</td>
<td>“Refers to the process of successively seeing deeper layers of meaning as a result of using school content as a lens for viewing or ‘re-seeing’ (Girod et al., 2003) the world”</td>
<td>“Before the course it was completely abstract, the concept of, earth in a larger context. It’s definitely less so the case now. I can think more about just how infinitesimally small the earth is in the grander scheme of things. . . . It recontextualizes everything that we’re doing here.”</td>
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<td>Experiential Value</td>
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<td>As a Whole</td>
<td>“Encompasses a perception that certain content is useful in immediate, everyday experience in the sense that it makes interactions with the world (and the content itself) more interesting, satisfying, or otherwise meaningful”</td>
<td>“With new student presentations coming thick and fast over the past couple of classes, I have been graced on the ways my peers think on certain scientific matters and how they present them. . . . Overall, this course has been able to open my eyes into many fields of science that are essential to figuring out the key questions floating around among the scientific community.”</td>
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<td>Intrinsically Meaningful</td>
<td>“Refers to a sense of enjoyment, interest, or satisfaction”</td>
<td>“Recently I went home for a weekend, and there were just significantly more stars that you could see, because there’s a lot less smog down there, and it was really cool to think about that. . . . I guess once you know all this stuff, you can’t help but kind of break it down as to like, how it all got here. I just feel like this class kind of made me question everything.”</td>
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<td>Pragmatically Useful</td>
<td>“Refers to perceived usefulness”</td>
<td>“This year I’m going to be taking AP Bio, and I think I’m going to use this in my knowledge if I can make connections in what I learned here to school.”</td>
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References


McPhetres, J. (2019). Oh, the things you don’t know: Awe promotes awareness of knowledge gaps and science interest. *Cognition and Emotion*. Advance online publication. doi: 10.1080/02699931.2019.1585331


Rudolph, J. L., & Horibe, S. (2016). What do we mean by science education for civic


