10-24-2022

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To cite this article: M. Gail Jones, Julianna Nieuwsma, K. Rende, Sarah Carrier, Emma Refvem, Cesar Delgado, Jill Grifenhagen & Pamela Huff (2022) Leveraging the epistemic emotion of awe as a pedagogical tool to teach science, International Journal of Science Education, 44:16, 2485-2504, DOI: https://doi.org/10.1080/09500693.2022.2133557

ABSTRACT

Awe is a complex emotion theorised to impact science learning and practice. In science education, awe has the potential to motivate explanation-seeking, promote conceptual change, and instill feelings of connectedness to the natural world. This exploratory study examined teachers' experiences with awe as well as their uses of awe in their science instruction. Thirty-four elementary (grades 4-5; *n* =14) and middle school (grades 6-7; *n* = 20) teachers completed a survey of awe perceptions and experiences and participated in a semi-structured interview. Results showed that science teachers report using awe-invoking classroom experiences in a variety of science disciplines with the intention of leveraging the emotional response in ways that facilitate learning outcomes and inspire long-term science interest. Teachers also reported numerous dispositional factors they perceived as being influential in governing awe experiences in science instruction including age, prior experiences, interest, curiosity, and the presence of co-occurring emotions. This study adds to the developing body of work around awe and science instruction, supports the findings from other fields related to the epistemic and self-transcendent nature of awe, and suggests that awe can be used to enhance science teaching and learning.

KEYWORDS

Attitude; conceptual change; motivation

Throughout history, science and the natural environment have evoked a sense of awe as humans struggle to understand the magnificent and the mysterious. Whether it is observing the aurora borealis, seeing a giant blue whale skeleton, or glimpsing a new world in pond water under the microscope, humans often experience *awe* as we think about science in new and unexpected ways. According to emerging research, awe may be a unique emotion that motivates exploration, understanding, and appreciation of the natural and physical world (Valdesolo et al., 2017). While scholars have begun to explore the potential of focusing attention to feelings of awe in enhancing science instructional components and outcomes, there is little research related to how students experience awe in science classrooms or how teachers use awe in their science instruction. In this exploratory study we examined how teachers report experiencing and defining awe as well as their reported uses of awe in science teaching.

Awe and wonder in science education

The Framework for K-12 Science (National Research Council, 2012) states that the over- arching goal of science education 'is to ensure that by the end of 12th grade, all students have some appreciation of the beauty and wonder of science' (p.1). The Framework goes even further to argue that:

> A rich science education has the potential to capture students' sense of wonder about the world and to spark their desire to continue learning about science throughout their lives. Research suggests that personal interest, experience, and enthusiasm—critical to children's learning of science at school or in other settings— may also be linked to later educational and career choices (p. 28).

But what is not clear is how educators encourage this appreciation for beauty and wonder and how to connect it with learning. Here we examine science teachers' perceptions and use of awe, an epistemic emotion (an emotion that relates to knowledge and the generation of knowledge, e.g. surprise, curiosity, and confusion) (Pekrun & Stephens, 2012). It has been argued that awe can promote science pedagogy that is 'intentionally designed to evoke meaning and connection by purposefully pushing toward a sense of the unknown, awe, and beauty' (Gilbert & Byers, 2017, p. 916).

While there is some research suggesting that awe can encourage engagement and learning in informal science settings (Krogh-Jespersen et al., 2020; Price et al., 2021), there is little work investigating the use of awe in formal science teaching. In a study involving inducing awe experiences in a laboratory setting, McPhetres (2019) showed that using nature videos to inspire awe promoted science interest and awareness of gaps in knowledge in adult participants. Additionally, Anderson et al. (2020) found that people who often experience awe tend to be more curious than those who do not report awe experiences, and that curiosity is highly correlated with predicted positive academic outcomes. In one of the few studies of awe in science education, Gottlieb et al. (2018) reported that students with higher reported awe dispositions (proneness to experience awe) held more accurate concepts of the nature of science. This study and those from the field of psychology suggest that pedagogy that integrates awe may be an effective tool for motivating students to want to know more about science, enhancing understanding of the nature of science, and promoting life-long appreciation of science and discovery. These promising findings provide evidence of the need for more research on awe in educational settings.

Theoretical framework

The present study explored science teachers' conceptualizations and uses of awe through a framework that includes three perspectives: (1) that awe is an epistemic and self-transcendent emotion that promotes scientific thinking, discovery, and prosocial science behaviours (e.g. Cruz, 2020; Gottlieb et al., 2018; Keltner & Haidt, 2003), (2) that the cognitive antecedents and consequences of awe are aligned with the cognitive processes known to underlie science learning (Valdesolo et al., 2017), and (3) that there are a multitude of dispositional factors and co-occurring emotions that govern awe experiences and impact cognitive and prosocial outcomes (Anderson et al., 2020; Shiota et al., 2007). Understanding science teachers' perceptions and uses of awe in accordance with these theories sheds insight into the potential for incorporating awe in science education and has implications for informing pedagogical best practices.

Awe: an epistemic emotion

In their foundational work, Keltner and Haidt (2003) defined awe as the feeling of encountering something literally or figuratively vast beyond comprehension coupled with a desire to understand the experience through cognitive accommodation, the Piagetian cognitive process where individuals must adjust mental schemas to assimilate new experiences (Keltner & Haidt, 2003; Piaget & Inhelder, 1969). Their quintessential example is the evocation of awe that comes from looking up at the night sky and contemplating the extensivity of the universe. In addition to describing physical or perceptual awe, Keltner and Haidt (2003) describe examples of conceptual awe such as perceptions of social importance, like meeting a celebrity or watching a prestigious speaker, or concepts with explanatory power such as the theory of relativity (Shiota et al., 2007). Cruz (2020) described awe as a self-transcendent emotion which decreases feelings of personal grandeur and induces feelings of connectedness to the wider world, both natural and social. While wonder is often experienced in tandem with awe, awe is associated with the emotions that are experienced when confronted with something 'incomprehensible or sublime' (Reinerman-Jones et al., 2013, p. 298), and wonder is typically associated with a feeling of reflection or inspiration (Weger & Wagemann, 2018), or as a response to something that leads to curiosity (Hadzigeorgiou, 2012). Curiosity has been defined as 'a psychological trait or disposition to prefer uncertainty, novelty, complexity, and exploration' or as 'novelty seeking or asking questions' (Luce & Hsi, 2015, p. 72). In this study we focus on awe as defined by Keltner and Haidt (2003) and Cruz (2020) that bounds awe to a feeling accompanied by a desire to understand the experience through cognitive accommodation.

Epistemic emotions like awe become activated when an individual attempts to gain knowledge and understanding, and these emotions play a critical role in how one learns and makes sense of the world (Valdesolo et al., 2017; Cruz, 2020). According to research, awe is uniquely triggered in situations where a person becomes aware of a gap in their knowledge (Valdesolo et al., 2017).

Awe as a self-transcendent emotion

Other scholars have focused on the development of a conceptualisation of awe that includes additional structural qualities related to self-transcendence (e.g. Cruz, 2020). Self-transcending emotions are characterised by a broadening of one's mindset and a shift in focus away from the self and into attunement with the greater natural and social world (Stellar et al., 2017). Shifts in one's perception of time, sense of self, or mental state are also considered facets of an awe experience and have been shown to mediate relationships with personal humility (Stellar et al., 2018). Studies have demonstrated how experiences of awe can elicit feelings of hyperfocus or attention (Prade & Saroglou, 2016; Sung & Yih, 2016), a sense of time slowing down (Rudd et al., 2012), and feelings of smallness and self-diminishment in the presence of grandness (van Elk et al., 2016). According to Cruz (2020), the phenomenon of feeling shifted away from oneself (e.g. through experiencing temporal or spatial shrinking or smallness) can promote epistemic humility and be a catalyst for positive social actions such as pro- environmental behaviours. For example, a multitude of renowned environmental activists like Jane Goodall, and Rachel Carson, describe being compelled by awe to pursue a lifetime of environmental activism and stewardship (Cruz, 2020).

Awe as a tool to promote scientific thinking and discovery

Cruz (2020) suggested that awe fulfills three key roles in scientific practice. First, awe pro- motes a focus and value to the objects being studied. Secondly, Cruz suggests that awe facilitates 'receptivity to the unusual and novel' (p. 9), and finally, awe is associated with a 'mode of understanding' (Cruz, 2020, p. 9) in the face of something like a new scientific discovery or phenomenon that is not expected or well-understood.

Science is often thought to be conducive to generating awe experiences since much of science in the natural world lies outside of the human scale and extends into extreme magnitudes of size and dimension (Valdesolo et al., 2017). For example, people often report experiencing awe when seeing large-scale phenomena such as the northern lights or experiencing a tornado. Studies exploring the relationship between awe and the natural world have included introducing participants to images of expansive natural scenery (e.g. Prade & Saroglou, 2016; Anderson et al., 2020), taking participants outside to stand under a grove of majestic trees (Piff et al., 2015), or immersing them in virtual reality to simulate vastness using digital panoramas of mountain ranges or outer space (Chirico et al., 2016). The experience of encountering something vast is thought to stimulate the cognitive processes involved in revising existing mental schemas in order to make sense of the awe-inducing stimulus. As such, scholars argue that awe is an integral part of scientific discovery and precipitates paradigm shifts and conceptual change (Gottlieb et al., 2018; Valdesolo et al., 2017).

While Keltner's and Haidt's (2003) theoretical work attributing awe to a sense of incomprehensible vastness as well as eliciting a need for cognitive change has been widely accepted as the archetypical definition of epistemological awe, other scholars have begun to explore alternative or supplementary characteristics of awe experiences. Weger and Wagemann (2018) have suggested that vastness and a need for cognitive change are not necessary to elicit awe and could be considered just two of many possible features of awe. They maintain that awe is characterised by determinants that govern the experience such as receptiveness and quality of attention.

Despite differences in theoretical and conceptual definitions, researchers and scholars agree that awe motivates individuals towards contemplation and encourages people to think abstractly and engage in science inquiry and exploration. Gottlieb et al. (2018) liken a person's psychological predisposition to experiencing awe to the qualities of having a scientific mind. In other work on scientists' perceptions of awe, Cuzzolino (2021) argued that the explanation-seeking that is associated with awe is related to the internal drive that may motivate individuals to pursue careers in science. In addition to promoting scientific exploration, awe is thought to encourage receptivity to the world, which is critical for scientific discovery and plays a role in the evaluation of scientific evidence

(Cruz, 2020). It is argued that it is precisely because of the open-ended nature of science that awe continues to drive ongoing investigation as new areas of research in science emerge (Schliesser, 2005).

Cognitive antecedents and consequences: awe can underlie science learning

In their generative framework for awe and science learning, Valdesolo et al. (2017) grounded their model in part on the effects of awe on cognitive processes associated with accommodation as well as in the emotion's cognitive antecedents. The factors, including *violations of expectations*, *a desire for explanation-seeking when confronted with gaps in knowledge*, and *cognitive accommodation or conceptual change* have been identified as components that undergird science learning and are linked to awe (Valdesolo et al., 2017). Violations of expectation have been shown to have a strong effect on learning outcomes including increased attention, awareness of gaps in knowledge, enhanced memory for the expectation-violating event, increased motivation and explanation-seeking, and causal-explanatory reasoning (Gottlieb et al., 2018; Valdesolo et al., 2017). Therefore, experiences of awe can potentially contribute to science learning.

Dispositional factors and co-occurring emotions that govern awe experiences

In their phenomenological inquiry of awe, Weger and Wagemann (2018) suggested that accommodation and vastness are two of many possible characteristics intrinsic to experiences of awe and that both phenomena can be further characterised by a range of situational and person-related attributes. Their study documented that the most significant parameter was inner-readiness and that stress and other negative emotions have the potential to inhibit one's experience of awe. They also noted that experiences of awe might be more frequently elicited when a person is already in a contemplative or observational mindset. In science education, observations are often reported to be a catalyst for the exploration of scientific phenomena and influence problem-solving, memory retention, and conceptual understanding (Johnston, 2009).

A person's awe proneness, or *dispositional awe,* has also been explored for its relation- ships to tolerance for uncertainty or ambiguity. According to Shiota et al. (2007), people who experience awe on a regular basis are more likely to have an increased tolerance of uncertainty. Schwartz (2008) argues that science often requires high levels of tolerance for the unknown, and therefore dispositional awe may promote open-mindedness and orientation to the natural world and an increased understanding of the nature of science. In their investigation into the relationship between awe and trait curiosity, Anderson et al. (2020) found that awe, openness to experience, and trait positive activation (e.g. being determined, attentive, alert, inspired, and active) were all predictors of curiosity which in turn predicts academic outcomes including work ethic, behavioural engagement, and academic self-efficacy.

Measuring the epistemic and self-Transcendent factors of awe

One of the most comprehensive measures developed for understanding states of awe is the Awe Experience Scale (Yaden et al., 2019; see Table 1). The scale includes six factors reported to be associated with awe experiences including *accommodation, vastness, connectedness, self-diminishment, time dilation,* and *physical sensations*. The factors *accommodation* and *vastness* are based in theories of epistemic emotion and involve the desire to change existing mental schemas to process unexpected information that challenges a person's current

Table 1. Awe experience scale factors.

Factor	Definition by Yaden et al., 2019	Awe Experience Scale Item Examples[1]
Accommodation	Changes in cognitive structures to process an experience.	'I found it hard to comprehend the experience in full.'
Vastness	Perceptual vastness is viewing something extremely large and/or vast. Conceptual vastness is contemplating vast ideas and/or concepts.	'I felt that I was in the presence of something grand.'
Physiological Responses	The physical reactions to the experience of awe.	'I had goosebumps.'
Connectedness	Sense of connection to surroundings, bigger picture, things 'greater' than one's self.	'I felt a sense of communion with all living things.'
Time Dilation	When sensation or perception of time alters during experience of awe.	'I sensed things momentarily slowing down.'
Self-diminishment	When bodily or subjective sense of self feels reduced or small due to or in comparison to the cause of awe.	'I felt my sense of self become somehow smaller.'

Note[1]. Item examples are from Yaden et al., 2019, p. 5.

understanding of the world (Shiota et al., 2007). The additional facets of *connectedness*, *self-diminishment, and time dilation* represent altered perceptions of oneself or one's consciousness and are considered to be aligned with prior research on the self-transcendent nature of awe (Chirico & Yaden, 2018). Though *physical responses* are not usually represented within measures of emotional response, Yaden et al. (2019) have argued that bodily reactions can occur during experiences that diminish one's sense of self.

Research questions

Guided by dominant theories of awe, this research explored science teachers' conceptualizations of awe, their perceptions of awe as a pedagogical tool, and the processes and procedures they use to incorporate awe experiences into their instruction. This study additionally investigated teachers' perceptions of dispositional factors that influence awe experiences. The following research questions guided the investigation: *(1) How do science teachers define and conceptualize awe? (2) How do science teachers describe the role and integration of awe in their science instruction* and *(3) What dispositional factors do science teachers perceive as governing experiences of awe?*

Methods

Participants

To investigate these research questions, an exploratory mixed-methods (Creswell, 2021) approach involving a written survey and follow-up interviews was used. Elementary and middle school science teachers from four local public school districts located in a south- eastern US state were invited to participate in the study through email invitations sent through teacher listservs and school system contacts. Selection criteria included public school teachers from grades 4–7 who taught science on a regular basis. These grades were specifically selected because they are transitional grades for students (developmentally) and these are grade ranges where students begin to show a decreased interest in science (Archer et al., 2010). All teachers who agreed to participate in the study were sent a link to provide written consent to participate and a link for the survey. Upon completion of the survey, teachers were contacted to schedule a follow-up interview. Teachers who completed the interview received a $25 gift card for their participation. A total of 34 science teachers (elementary $n = 14$, middle school $n = 20$) volunteered to participate in the study. The sample included 30 women and four men, and participants self-identified as White ($n = 25$), Black ($n = 9$), or Multiracial ($n = 2$). The mean years of teaching experience was 12 years and the mean age bracket of participants was 35–44 years old.

Data sources

Awe experience survey

Participants completed the validated *Awe Experience Scale* (AWE-S; Yaden et al., 2019). Using exploratory and confirmatory factor analyses, Yaden et al. (2019) reported that the AWE-S has a stable 6-factor structure (CFI = .905; RMSEA = .054) with high internal reliability. The six factors were time dilation, self-diminishment, connectedness, vastness, physical sensations, and accommodation. The assessment has also been shown to have adequate convergent, divergent and construct validity (Yaden et al., 2019). Each factor in the AWE-S includes 5 items for a total of 30 items. Yaden et al. (2019) reported the standardised alphas were: $\alpha = .91$ for time dilation, $\alpha = .89$ for self-diminishment, $\alpha = .87$ for connectedness, $\alpha = .85$ for vastness, $\alpha = .81$ for physical sensations, and $\alpha = .80$ for accommodation with a total scale reliability of $\alpha = .93$. The authors reported that a higher total AWE-S score indicates a more subjectively intense experience for the respondent.

The AWE-S directions asked participants to describe and reflect on a recent, intense, and personal experience of awe and then respond to a series of statements regarding the experience using a seven-point Likert scale (ranging from strongly disagree to strongly agree). Examples of items from the survey included ‘I perceived something that was much larger than me,’ and ‘I felt challenged to understand the experience.’ All of the statements corresponded to one of the six factors associated with awe experiences (Yaden et al., 2019). Each factor included five statements for a total of 30 items.

Six instruction-related items (described below) were developed by the authors and added to the AWE-S survey to capture awe related to teaching and teachers. The new items were reviewed by a panel of experts that consisted of two experienced science teachers and three education researchers. The total survey was piloted with a sample of four science teachers and the new items were revised for clarity. For these new items, teachers were asked to rate their level of agreement on a seven-point Likert scale. The new items included: ‘I have experienced awe in the classroom,’ ‘I have experienced awe in informal education settings (ex. Museums, zoos, summer camps),’ ‘I regularly try to elicit feelings of awe in my students,’ ‘Experiences that evoke awe can be planned,’ and ‘It is easy to incorporate awe into my instruction.’ The survey was distributed to participants through Qualtrics and took approximately 20 min to complete.

Teacher interviews

A 30-minute semi-structured interview was designed to capture the specific contexts and details of teachers’ experiences with awe and their uses of awe in instruction. All the teachers who completed the survey were interviewed. The interview protocol was reviewed by the expert panel (described above), piloted with a sample of four teachers, and then revised for language clarity. The interview protocol included 17 questions, such as ‘What is your definition of awe?’, ‘What are the ingredients to an awesome experience?’ and ‘How have you intentionally or unintentionally integrated or leveraged awe-inspiring experiences in your science instruction?’ Interviewers probed participants for the pedagogical approaches and contexts associated with evoking awe as well as the dispositional factors that govern awe experiences. The interviews were audio-recorded and transcribed for analysis.

Analyses

Awe experience survey

Likert responses for the AWE-S and the instruction-related items were converted to a numerical value (e.g. 1 = strongly disagree, 4 = neutral, 7 = strongly agree) to calculate each participant's factor scores and a total awe-experience score. Factor scores included the mean of each of the five items associated with the individual factor numerical values and the factor score represents the strength of emotion or mental state associated with each factor. The total awe score was composed of the mean of all items and includes the combined factor experiences. Each of the teachers' awe experience examples was coded as science-related or non-science related and analyzed for differences by context. Awe examples given on the survey were coded as receiving a high or low awe score if their mean combined individual awe factor score was above or equal to 4.5 (high) or below 4.5 (low). A high awe score for a factor indicated the awe experiences had a strong effect of that factor on the individuals (e.g. a vastness score of 5.6 would mean the individual experienced a strong sense of vastness from their awe experience).

Teacher interviews

Using ATLAS.ti 8, interview transcripts were reviewed for *a priori* codes derived from the three perspectives informing our theoretical framework. These codes included Yaden et al.'s (2019) six factors of awe (*accommodation, vastness, connectedness, self-diminishment, time dilation, and physical sensations*) as well as for the overarching themes of *instruction*, *dispositional factors* that govern awe experiences, and the presence of *co- occurring emotions*. Included within the theme of accommodation were subcodes for *antecedent factors* (e.g. violations of expectation that make knowledge gaps salient, uncertainty or cognitive dissonance, motivation or desire to close knowledge gaps) purported to precede cognitive accommodation and conceptual change. Open-coding identified additional sub-themes within *instruction* (e.g. context of experience, learning goals, pedagogical approaches, and student response), *dispositional factors* (e.g. interest, age, open- ness to experiences) and *co-occurring emotions* (e.g. surprise, amazement, stress). After a codebook was developed, axial coding was applied to provide additional insight on relationships between the coded-for factors. Twenty percent of transcripts were independently coded by two coders achieving an interrater reliability of 0.8 for the 26 codes that comprised the codebook (Krippendorff, 2011). Once interrater reliability was determined, the remaining transcripts were coded individually then reviewed for concurrence by two additional members of the research team. All participants' names have been replaced with a pseudonym to protect their anonymity.

Results

Teachers' personal definitions and conceptions of awe (Research question 1)

Teachers' general perceptions of awe experiences

Teachers' perceptions and experiences with awe in their personal lives and in their science instruction were documented in the initial survey and were clarified in sub- sequent interviews. Survey results revealed all but one of the teachers (97%) have experienced awe when teaching science, and all but two of the teachers (94%) have experienced awe in informal education settings (e.g. museums, zoos). Of those teachers who reported experiencing awe in their teaching, most (82%) reported regularly trying to elicit feelings of awe in their students during instruction. Teachers agreed that awe experiences could both be intentional and unplanned. One of the teachers expressed a few that 'every lesson can't start with an awe experience' citing time, costs, and standards requirements as limiting factors. Approximately 40 percent of teachers did *not* agree that it is easy to incorporate awe into their instruction. Science teachers' responses were mixed on survey items inquiring about administrative support for incorporating awe into instruction. One-third (35%) of teachers reported not feeling encouraged by their administrators to incorporate awe-inspiring experiences into their science lessons.

Teachers' reported examples of awe and congruence with the awe experience scale (AWE-S)

The awe examples reported by the teacher participants in the survey were diverse and included experiences like nature encounters, teaching experiences, and experiences in social contexts. The teachers' group mean scores for the factors included *vastness* (M= 5.32 SD = 1.00), *physical sensations* (M = 5.14 SD = 1.15), *accommodation* (M = 5.04 SD = 1.31), *time dilation* (M = 4.83 SD = 1.27), *connectedness* (M = 4.75 SD = 1.18), and *self-diminishment* (M = 4.15 SD = 1.31).

The total group awe score was considered to be high (M = 4.93 SD = 0.89).

The analyses of the science and non-science examples of awe found that a majority of the examples that received a total awe score of 4.5 or higher were experiences that were set in science contexts (see Table 2) and tended to involve nature (e.g. watching a sunset, encountering wildlife, exploring space). Highly-scored non-science examples came from a variety of social contexts including examples such as witnessing a student or family member being successful in a challenging situation. Science examples scored highly for the individual factors of accommodation, vastness, physical sensation, and connected- ness. Examples involving nature scored particularly high for these factors. One of the teachers reported this instance of awe:

> My wife and I go for a walk in the early evenings these days, and it is like we have been reintroduced to the sky and all of its glory. With the sun going down, the clouds coming and going, the reflections of light, the changing of colors, with spring popping out all over, and with time we have been able to take in at least some of the life of Earth as it goes about its business. It is terrific to take it in and has been a calming, reassuring presence that we look forward to. I really appreciate relearning the connections we have to the natural world.

This teacher's response resulted in a score of 5.4 for accommodation, 7 for vastness, 6.6 for connectedness, and 5.8 for physiological.

Table 2. Awe factor scores by science and non-science contexts.

	Frequency	Percentage
High awe factor scores- science	14	41.18%
High awe factor scores- non-science	10	29.41%
Low factor scores- science	6	17.65%
Low factor scores- non-science	4	11.76%

Note. A high awe factor score was defined as a score of 4.5 or higher and a low factor score was below 4.5.

The analysis of awe experiences for differences by context revealed no differences, with 70% of science-based experiences and 71% of non-science-based experiences having high awe factor scores. A majority of the awe experiences (71%)

were science-based.

During the interview, teachers were asked to describe their personal understandings of awe, what ‘ingredients’ they perceived as being required for an awe experience, and the contexts in which they have experienced awe. It is important to note that we wanted to document teachers’ perceptions of awe, even if these perceptions may have varied from those used by researchers.

The teachers’ reports of awe included personal experiences of awe and awe in the context of science teaching or learning. To explore personal conceptions and definitions, the interview transcripts were analyzed for the a priori codes of *accommodation, vastness, connectedness, self-diminishment, physical responses,* and *time dilation*.

Accommodation

Of the six awe factors analyzed, accommodation was the factor most frequently noted in the interviews. All but one of the teachers (33 of 34) indicated they associated awe with changes in thinking. These changes were often described as instances of enlightenment or understanding (e.g. ‘aha moments,’ or ‘light bulbs going off’) after encountering a new phenomenon or experience. For example, Molly defined awe as ‘seeing something for the first time, or in a different way, or that ‘aha’ moment when you first understand or notice something that you hadn’t noticed before.’ Other teachers described achieving accommodation as part of a process that included other co-occurring emotions or antecedents. According to Wendy, ‘having that curiosity and then actually understanding it [would] be an ‘aha’ moment.’

Teachers described students’ embodiment of accommodation in awe in terms of comprehension or satisfaction with overcoming a mental hurdle or achieving a learning goal. Sally described the relationship between cognitive processes and awe saying, ‘students make connections to something that was abstract and is now a part of their knowledge. When I see their light bulb or they get it they’re going through that awe state.’ According to Aurora, ‘I think for me as a teacher, I can see

[awe] if they kind of have that aha moment about something that they've been struggling with.'

Vastness

The concept of vastness appeared in 26 out of 34 teacher responses. Several teachers included vastness in their definition of awe or as an ingredient needed for an awesome experience. Some discussed vastness through concepts of size and scale. For example, Jennifer's definition stated that awe 'can be little or big. It makes you stop and think, wow, that's a lot bigger than I was expecting.' Rather than focusing on physical or perceptual magnitude, other teachers discussed vastness through a more social or theoretical view of the construct (e.g. meeting an idol, listening to a famous speaker). For example, Cathy said, 'people and the acts that those people are doing or things that they are saying can be awe-inspiring.' In her definition of awe, Barbara referenced vastness as 'greatness

… or somebody who is doing something that potentially could impact generations or impacts lives or impact the future of how we do things in STEM.' Vastness was also reported as occurring during science instruction. Anise described, 'We watch a video where we look at the sun then zoom out past other massive stars. There is awe in that concept and them trying to wrap their heads around how tiny we are in comparison.'

Connectedness

Ideas of connectedness were mentioned in 15 out of 34 teacher interviews and often straddled social and scientific realms. For example, Elise shared 'I like to think of how things are all connected. When we talk about ecosystems [in class], you can see how humans are connected to trash and pollution issues.' Barbara stated 'I think COVID is presenting itself with some awe, as this is where science becomes so real. You have a global situation going on and you have a global connection with it.' Themes of connectedness often appeared alongside references to physical and perceptual vastness. When providing an example of something they found perceptually vast, Jade referenced her experiences with trying to comprehend the enormity of the COVID-19 pandemic saying, ‘I think the whole coronavirus thing is inspiring; that one little germ can shut down the whole entire world.’

Teachers’ descriptions of connectedness in the context of teaching were generally focused on making connections between concepts and students’ lives as a way to facilitate learning outcomes or accommodation (35%, n = 12) rather than describing connections to their own awe experiences. Sarah described, ‘I always have to ask them to make a connection with real life. So, when they do that you can almost see the light bulb go off in their head. It’s like, ‘oh, okay I understand now’.’

Self-diminishment, physical responses, time dilation

Two other awe factors, self-diminishment and physiological responses, were represented in teachers’ discussions of awe. Four out of five teachers reported experiencing self- diminishment when comparing themselves to the wider universe. Jade reported, ‘We started doing space stuff [in class] and I’m in awe of how small we are in the realm of the universe. There’s so much more out there and when you put this in perspective, we’re like absolutely nothing.’ Physical responses during awe experiences were noted in 16 interview transcripts. When defining awe, Jennifer reported, ‘It is something that just kind of makes you stop, maybe makes your jaw drop or kind of takes your breath away.’ The majority of descriptions of physical responses that emerged in participant interviews were related to observations of awe embodiment in their students and included witnessing jaws dropping or hearing verbal exclamations (e.g. saying ooh, ah, or wow; gasping). A variety of items related to observations of physical awe responses were also included in the initial survey. Teachers’ survey responses identified moderate to strong agreement with physical responses to awe including gasping or exclaiming aloud (n = 26), or conversely getting very quiet (n = 19), along with widening eyes (n= 25) were the most recognisable physical responses to an awe experience. The only factor to not appear in any of the interviews was time dilation.

Teachers' contextual integration of awe in science instruction (Research question 2)

During the interviews, teachers were asked to describe whether awe fit into their instruction, how they intentionally or unintentionally leveraged awe experiences during teaching, and how students relate to experiences of awe in the classroom. Throughout the interviews there were numerous descriptions of awe being integrated into science instruction (see Table 3).

Teachers' conceptualizations of the role of awe in science instruction

Teachers noted that evoking heightened emotions during instruction influenced levels of students' engagement, increased desire to achieve learning outcomes, and promoted changes in thinking. Nearly all teachers (94%) reported attempting to induce awe in students in order to spark initial engagement or to capture their attention. The contexts for the experiences were typically described as being discrepant events, demonstrations, and showing students videos or

Table 3. Teachers' integration of awe in science instruction.

Discipline	Frequency	Related Topics	Lesson Examples
Physics	72 (33%)	Astrophysics, circuits, density, electricity, energy, forces, heat, gravity, kinetics, optics, waves	Wave generator; slinkies and wave dynamics; light lab; sound lab; moon phases; interplanetary distance lab; hot air balloons; sundials; Bernoulli's Principle floating ping-pong balls; paper airplanes; circuit lab; planetary motion
Biology	60 (28%)	Botany, cells, ecology, ecosystems, evolutions, organisms, life cycle, microbiology	Botanical garden, museum virtual tour; breadmaking; hydroponics lab; camera trap citizen science; squid dissection; plant cell microscopy; butterfly life cycles; virology
Earth Science	43 (20%)	Clouds, climate, earth structure, fossils, geology, natural disasters, plate tectonics, seismic activity, volcanoes, water cycle	Continental drift mapping; shake tables; weathering cubes; cup and sponge precipitation; cloud in a bottle
Chemistry	30 (14%)	Acids and bases, chemical properties, chemical reactions, mixtures, solutions, states of matter	Rock salt ice cream; cabbage juice acids and bases; ball and ring chemistry experiment; bread making; chemical and physical change lab; properties of water; alka seltzer tablets; laundry detergent lab; chemical rockets
Health	10 (5%)	Anatomy, body systems, human genetics, human physiology, nutrition	Cow or sheep eyeball dissections; frog dissection; organ system labs
Engineering	2 (1%)	3-D printing, structural engineering, nanotechnology	Robotics lab; house of cards; model building; bridge building

Note. Lesson examples were given by teachers during interviews.

photographs. According to Jane, 'I like to try to do something that catches the kids' attention and makes them go, 'whoa!'.' Further, 91% (*n* = 31) of teachers described the attention-grabbing benefits of awe-inspiring experiences as being part of an instructional plan that would lead to learning outcomes. Veronica described this tactic as 'baiting students into wanting to learn more.' Between these beginning and end 'stages' of the awe-inspiring learning experiences, teachers reported intentionally creating violations of expectation (68%) and observing that the awe moment motivated students to engage in explanation-seeking (82%).

Violations of Expectation. Sixty-eight percent of the teachers described generating heightened emotions by intentionally creating knowledge violations through the introduction of something that was 'unanticipated' or 'unexpected.' According to Mitch, 'I know I can awe an entire classroom if I make a deviant enough experiment … if it deviates from their expectations.' Teachers reported that students experiencing violations of expectation would display a variety of *physical responses* including gasping or making verbal exclamations. Recalling an unexpected result during a discrepant event, Aurora said, 'They weren't expecting [the experiment] to change as quickly as it did. And you know there were some like 'oohs and ahhs' and 'oh my goodness, look at that' and different reactions like that.' Barbara also described that students would engage in discourse about a violation event and ask questions like 'Is this even real?,' or 'How did you get it to do that?'

Gaps in Knowledge and the Desire to Close Them. Teachers noted that awe-inspiring experiences would typically leave students 'shocked' and with unanswered questions. Ben described his own personal experience of uncertainty or cognitive dissonance after a violation of expectation saying, 'I think when you have something unexplainable it's hard to know how to react to it. It's like you see or experience something and your mind at that moment is trying to process and understand everything that's happening.' Within the context of the classroom, Jennifer described uncertainty as, 'That not-knowing feeling. We made guesses, we hypothesised about what was going to happen, but then, just not really knowing what was going to happen.' Teachers' observations of students' experiencing uncertainty included exhibiting a visible desire to understand the experience, e.g.

‘their eyes are open more they’re listening and they’re trying to soak it up like they want to learn more’, as well as asking explanation-seeking questions like ‘How did that happen?’ or ‘How is that possible?’

Leveraging the heightened emotions that resulted from having knowledge gaps made salient was a critical part of motivating students to want to achieve learning outcomes. Teachers reported capitalising on students’ motivation to understand the experience by encouraging time and space for students to wrestle with uncertainty and get their ‘wheels turning.’ According to Regina, ‘I just want experiences of awe to drive my students to have questions and then to answer their own questions.’ Several teachers referenced situating awe experiences within inquiry-based learning or the engage and explore phases of the 5E lesson model (Bybee & Landes, 1990). Giving students time to work through their questions was considered a critical component needed to bridge the gap between the knowledge violation and learning outcomes. Amelia described the pedagogical process from engagement through inquiry:

> A lot of times I try to use it like that hook piece to get them excited about something. Or to get them thinking, asking questions so that they’re more invested because they want to know, how is this possible? And then we’re able to investigate, to try and figure it out.

Perceived dispositional factors that govern awe experiences (Research question 3)

The teachers identified several dispositional factors that they perceived as mediating awe experiences including students’ interest, prior knowledge, age, open-mindedness, and other emotions like anger or stress.

Prior experience

Students’ prior experience with the science topics being taught was heavily cited (91%, n= 31) as impacting whether or not an instructional experience elicits awe. For example, Ann reflected that, ‘We all have different levels of experiences. Your previous experiences are going to dictate your awe level.’ Teachers mentioned that students who have seen a discrepant event or a science demonstration before are not likely to be awed by it. Anna noted, ‘you will be more awe inspired if it’s something that caught you off guard or that wasn’t something that you’ve seen many times before.’ One teacher described that they unintentionally evoked awe in students during a demonstration with an effervescent tablet because they had misjudged students’ familiarity or prior experience with what they considered to be a common household item. Teachers described science as a ripe context for inducing frequent evocations of awe due to the propensity of science for violating expectations. According to Laina, ‘I do feel like a lot of what creates awe are the expectations that we hold. So, depending on the person’s expectations that can have an impact on their frequency of experiencing awe.’

Interest

Thirty-eight percent of teachers (n = 13) identified that interest, or a desire to give selective attention to an activity or experience, governed students’ experiences with awe. Interest was described as driving knowledge-seeking behaviours in terms of initial engagement with the topic, but also in terms of whether interest was sufficient to motivate students to want to close their knowledge gaps. Teachers conceptualised interest as something that existed prior to an awe experience, but also that could be impacted or elevated as a result of experiencing awe. Elise described evoking awe as part of motivational interest-building, saying ‘Building interest with awe as a teacher is like trying to give some background knowledge and build excitement.’ Teachers such as Lilly pointed out that interest is a highly personal emotion that governs the motivational components of awe. ‘I think awe is about what motivates you. Things that motivate you might not motivate somebody else or interest them.’ Teachers like Mitch reflected on the challenges of evoking awe in students with limited prior experience and interest in the material being presented:

> If students are interested in a content area, they may be more susceptible to awe in that area, but making somebody go through this motion of becoming interested enough to evoke awe is going to be more difficult than if they’re already invested.

Age and development

Related to prior experience, *age* (62%, *n* = 21) was also mentioned as an influential factor and was described in terms of development and exposure to life experiences. According to the teachers, 'With younger kids there's so many new experiences that they don't have answers for or are able to developmentally understand' or 'I think children experience it more easily than adults because there's still a lot of things they haven't experienced yet or things that haven't become commonplace to them.' Teachers also commented that children may be more dispositionally-primed to have awe experiences saying, 'Openness to new ideas can help people experience awe and that may correlate with age.'

Personal disposition and comfort with cognitive uncertainty

Forty-five percent of the science teachers (*n* = 15) noted that some students are likely to tolerate both the positive and negative emotions of an awe experience and are thus pre- disposed to reacting to awe. Many teachers perceived that some people are just naturally more open to 'being wowed' (24%, *n* = 8). According to Elise, 'I think it just has a lot to do with, you know, your mindset and your personality and such.' Teachers related predisposition towards awe as being associated with other positive emotions such as happiness and optimism while low predisposition for awe was associated with negativity and close- mindedness. Aurora reflected,

> I think there are people that are naturally optimistic and people that are naturally pessimistic. I think that there are people that naturally are going to kind of seek out those aha moments or recognize them a little more and appreciate them a little more.

Teachers used descriptors like 'stick in the mud' to describe others with low predispositions for awe. Another teacher suggested that predisposition for experiencing awe could be mutable, reporting that if students 'are encouraged to question things and they're exposed to a lot of different things that might make them more naturally inclined to seek out experiences that are full of awe.'

Conversely, teachers described that some people may be more comfortable with cognitive uncertainty and being exposed to things that are unfamiliar (21%, *n* =

7) than others. Kevin noted that, compared to people who do not frequently experience awe, those who seek out or enjoy awe experiences are ‘people who don’t mind being wrong who are not afraid of being wrong. We’re not afraid of making mistakes.’ Ben described discomfort with cognitive uncertainty as ‘some people might have a tough time trying to explain something that’s indescribable and might try to shut that out at times because it doesn’t fit in their nice box.’ Teachers noted that the influence of other co-occurring emotions such as confusion or stress on a students’ ability to tolerate uncertainty. Stu- dents who felt stressed, either induced by the uncertainty of the awe experience or by external factors, might be limited in their ability to experience awe or their motivation to pursue cognitive closure. Cathy summarised:

> I think, um it, the emotional state can definitely impact how we experience awe, I think, awe’s not necessarily always something that makes you feel positive or good inside, it can also be something that it’s awesome, but it’s scary, and not necessarily giving you positive feelings. So I think that our emotional state, whether we’re feeling anxious about something, excited about something, sad about something, can definitely change the way in which we experience awe.

Teachers also reported that students who may be experiencing stress outside of school may be limited in their ability or desire to engage with experiences designed to evoke awe. According to several teachers, the ability to focus or give attention to an awe experience in the presence of other co-occurring emotions was perceived to play a role. Aurora stated, ‘I think if you are sad or angry or kind of in those negative feelings. I think it’s going to be a little bit harder for you to maybe pay attention to things that could be awe inspiring.’ Ava said, ‘What happened at their home last night or if they don’t have something to eat. They’re not going to be in the moment of what you’re really doing and get something out of [instruction] if their focus is somewhere else.’

Discussion

Our research demonstrates that the ways teachers think about awe and incorporate it into their instruction are related to the goals of science education by focusing on how students learn, how science is connected to students' lives, helping students be open to new ideas, and helping students see relevancy (NGSS Lead States, 2013). While we are not the first researchers to investigate awe in educational settings, this study is one of the first to examine teachers' perceptions and reported use of awe in elementary and secondary science education contexts.

The world of science is a rich resource for awe experiences. Science is conducive for instilling awe experiences because awe experiences often involve topics associated with size and scale (Valdesolo et al., 2017), beauty (Keltner & Haidt, 2003; Valdesolo et al., 2017), nature (Valdesolo et al., 2017), accommodation, vastness, connectedness, self- diminishment, and physiological responses (Yaden et al., 2019) Our results support the descriptions and findings of these studies. In the awe experience survey we administered to teachers, 71% of the awe examples provided by a participant involved a scientific concept. These science examples of teachers' engagement with awe included experiences that instilled high feelings of accommodation, vastness, connectedness, self-diminishment, and physiological responses, though not time dilation. One of the most frequently occurring topics among our responses involved the beauty and characteristics of nature; these findings mimicked the findings of the original awe experience survey validation study by Yaden et al. (2019). Our interview results reported science teachers found awe in the four core science disciplines (physics, biology, earth science, and chemistry) in addition to other science-related disciplines (e.g. health and engineering). In addition, when defining and describing their perspectives of awe, science teachers often incorporated elements of awe factors identified by prior research, in their responses. Teachers dis- cussed their own experiences with awe as well as those of their students.

In their interviews, teachers described their reasoning for incorporating awe into their instruction. Reasoning included sparking engagement in students, generating question- and answer-seeking behaviour, and promoting changes in thinking. Teachers' rationale for using awe as a pedagogical tool reflects calls for science educators to promote inquiry, curiosity, and critical thinking in their students

(National Research Council, 2012). The teachers' desire to use awe as a way to promote engagement, if fully developed, could encourage critical thinking (Cruz, 2020) and explanation-seeking behaviour (Cuzzolino, 2021). But before the full benefits of awe as an instructional tool can be realised, teachers may need to develop fuller understandings of awe and how awe can support learning.

In this study, teachers reported interest as a motivator in students to become initially engaged and curious with a specific science topic. But this view of awe does not take into account the benefits that researchers argue can accompany an awe experience. For example, as noted above, awe experiences can promote cognitive accommodation and new perspectives about phenomena. The interviews showed some teachers tended to view awe as more of a tool to promote initial motivation rather than an experience that promoted learning.

Accommodation and vastness are perceived as two of the most critical features needed to promote an awe experience (Keltner & Haidt, 2003). In the present study, interview transcript analyses found accommodation and vastness to be the two most frequently occurring features mentioned in teachers' discussion of awe; however, they were not the only features to appear and were not always present in a teacher's discussion of awe. Other features, such as connectedness, self-diminishment, inner-readiness, or awe proneness also occurred as being important agents of an awe experience according to participants. This result supports Weger and Wagemann's (2018) literature review and phenomenological study findings of accommodation and vastness not needing to be present for an awe experience. Weger and Wagemann argue that receptiveness and quality of attention are just as critical of a feature of awe as accommodation and vastness. Considering students' receptiveness for an awe experience is crucial for teachers wanting to implement awe into their science instruction. In our study, teachers reported students who are not emotionally and cognitively available for an awe experience, due to distracting emotions such as stress, anger, and sadness can limit a student's ability to evoke awe.

The axial coding revealed that most themes corresponded to aspects or components of awe previously identified in the psychology literature. Although awe has been described previously in social contexts (Cruz, 2020), the application of awe to social aspects of instruction is novel. Teachers described being awed by students' social behaviours or dealing with adversity or challenging situations. Further research is needed to determine if these types of reported awe experiences include the range of awe components described in the literature such as accommodation, hyperfocus, or self-diminishment (Prade & Saroglou, 2016; Stellar et al., 2018).

Limitations

This study has several limitations that are important to keep in mind. Awe experiences shared by participants in both the survey and interview are self-reported anecdotes of awe experiences. While teachers talked about witnessing awe moments in their students, these second-hand accounts are from the teacher's perspectives and do not reflect the students' viewpoints on if the activity or lesson instilled a sense of awe in them. Awe experiences are unique and personal to the individual person so responses provided by participants can be varied. Another limitation is the participants were volunteers and it is likely that only those teachers who have an interest in the topic may have responded to the invitation to participate in the study.

Implications/Future research

Our exploratory research highlights the potential learning benefits that the intentional inclusion of awe experiences in science instruction can provide. Such experiences can engage students in content instruction, increase their interest and desire to learn, activate emotional connections that encourage learning (NRC, 2005), and promote students' connections through shared experiences. However, there are a number of areas where research is needed to better understand awe as a pedagogical tool. One of the first challenges for researchers is how to measure the components of awe in students, particularly younger children such as those in middle childhood taught by the teachers in this study. We also need to know whether teachers' awe experiences influence the awe experiences of their students.

Furthermore, we need to know how much of a violation of expectation is needed for awe to promote a need for accommodation. When teachers utilise awe as an instructional tool, where in the lesson is awe most impactful? Is awe most effective in the engagement component of a lesson or as part of observations of phenomena? Additional research is needed to determine whether teachers who use awe as a tool to create connectedness and self-diminishment are able to provoke more accommodation or cognitive engagement. And finally, with additional research we can determine whether awe influences student learning and achievement. We need to know if awe moves students beyond curiosity about science to learning more about science.

Conclusion

The results of this study build on existing theoretical and empirical work and add new evidence to support the use of awe as a pedagogical tool. Though teachers were not familiar with the theories associated with awe at the time of the study, their knowledge and practices suggest that many were already attempting to leverage the awe experiences in their teaching in ways that align with prior research. This research also provides new data on the dispositional factors which have the potential to impact the ways in which students receive and respond to awe experiences. Together, these contributions are beneficial for creating an empirically and theoretically grounded model of awe as a teaching tool. Pedagogical approaches such as the 5E model or inquiry-based learning may provide an appropriate scaffold within which awe-integration could be deployed. Additionally, future work is needed to explore the impacts of awe experiences in science classrooms on student learning outcomes.

Ethics statement

This study was approved by the NC State University Institutional Review Board study number [20789].

Disclosure statement

No potential conflict of interest was reported by the author(s).

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