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Spirituality of Science:
Implications for Meaning, Well-being, and Learning

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Spirituality of Science: Implications for Meaning, Well-being, and Learning

Abstract:

Scientists often refer to spiritual experiences with science. This research addresses this novel component of science attitudes—*spirituality of science*: feelings of meaning, awe, and connection derived through scientific ideas. Three studies ($N = 1197$) examined individual differences in Spirituality of Science (SoS) and its benefits for well-being, meaning, and learning. Spirituality of Science was related to belief in science, but unlike other science attitudes SoS was also associated with trait awe and general spirituality (Study 1). Spirituality of Science also predicted meaning in life and emotional well-being in a group of atheists and agnostics, showing that scientific sources of spirituality can provide similar psychological benefits as religious spirituality (Study 2). Finally, Spirituality of Science predicted stronger engagement and recall of scientific information (Study 3). Results provide support for an experience of spirituality related to science, with benefits for meaning, well-being and learning.

148 words.

Keywords: *Awe, Science attitudes, Science learning, Well-being, Meaning, Spirituality,*

Spirituality of Science: Implications for Meaning, Well-being, and Learning

Science is the empirical method of knowing based on systematic observation and theorization. But science is more than cold calculation, it reveals the nature of the world and ourselves, the interconnection between living things, and yields awe-inspiring discoveries and theories that create meaning, feelings of connection, and wonder. We argue here that there is something deeper to the scientific experience —beyond mere cognitive understanding and intellectual agreement—that may be best described as a spiritual experience. As Carl Sagan wrote: “When we recognize our place in an immensity of light years and in the passage of ages, when we grasp the intricacy, beauty and subtlety of life, then that soaring feeling, that sense of elation and humility combined, is surely spiritual” (1996).

This project addresses that important but unstudied component of science attitudes, *spirituality of science*: the experience of meaning, connection, and awe derived from scientific ideas, theories, and the scientific process. Spirituality of science is more than just liking for science, or belief in science as a way of knowing. Rather, spirituality of science reflects the deeply positive transcendent experiences that emerge from interactions with science that include feelings of connection, meaning, and awe. Not all people feel spirituality through science, but those who do may reap some important benefits. This includes direct benefits on engagement in science, and better science learning and performance. And more broadly, spirituality of science may provide some important advantages that parallel those of religious spirituality, including benefits for general well-being and overall feelings of meaning in life.

Spirituality and Science

How can science be a source of spirituality? It is sometimes unclear what is meant by spirituality and how it is distinct from religious belief. But religion generally refers to the

external factors of belief such as group affiliation and practices, whereas spirituality generally refers to the more internal and personal aspects of belief (Pargament, 1999; Zinnbauer et al., 1997). Definitions of spirituality generally emphasize the role transcendent emotion, connection, and search for meaning (Piedmont, 1999; Emmons, 1999). In other words, spirituality relates to the experience itself (Saucier & Skrzypińska, 2006; Wixwat, & Saucier, 2021).

First, spirituality is characterized by experiences of transcendent emotion (Fredrickson, 2002; Van Cappellen et al, 2016), such as feelings of profoundness and beauty (Cohen, Gruber, & Keltner, 2010). Awe, an emotion defined by perceptions of wonder and vastness (Keltner & Haidt, 2003; Shitoa et al., 2007), is of particular relevance to spirituality. Both religious and non-religious people feel awe and “small self” in response to spiritual experiences, but non-religious report spiritual experiences from secular sources, e.g., experiences in nature (Preston & Shin, 2017). Experimental manipulations of awe have been shown to increase spiritual activities (Van Cappellen & Saroglou, 2012), and also to enhance more abstract concepts of God (Johnson et al., 2019). Spiritual experiences are also characterized by feelings of connection and meaningfulness (Steger, 2013; De Klerk, 2005). The meaning in life is an important human motivation (Heine, Proulx, & Vohs, 2006), and where meaning in life is found it is typically through three elements: having purpose, having significance, and sense-making (Heintzeman, & King, 2014; Martela & Steger, 2016). The meaningfulness associated with spirituality can contribute to numerous other positive life outcomes, such as workplace satisfaction (De Klerk, 2005) and addiction recovery (Pardini et al., 2000) as well as numerous studies demonstrating benefits for overall well-being (Cohen, 2002; Holder, Coleman, & Wallace, 2010), and physical health (Thoresen, 1999; Weaver et al., 2006).

These same characteristics of spirituality can be also derived from experiences with science. Science evokes strong feelings of awe (Gottlieb, Lombrozo, & Keltner, 2015; Valdesolo et al., 2016a; 2016b) via the majesty of grand scientific theories and their implications for understanding the nature of ourselves and the universe. For example, predisposition towards awe is associated with improved scientific thinking (Gottlieb, Keltner, & Lombrozo, 2015), and manipulations that activate feelings of awe also promote an interest in science learning. (McPhetres, 2019). Science likewise can provide a powerful sense of *meaning*, an important aspect of spiritual experiences, through strong explanatory coherence and structure (Preston & Epley 2005). That is, scientific theories help one to make sense of one's life and the universe, and in doing so creates an alternative source to the meaning provided by religion (Preston & Epley, 2009; Rutjens, van Harreveld, & van der Pligt, 2013). Among non-religious people, for instance, science may provide important existential meaning that can buffer against fear of death in the same way that religious meaning does (Farias et al., 2013).

Benefits of Spirituality of Science

If spirituality can be experienced through science, this has some potential positive implications. Spirituality of science may be beneficial in promoting engagement and learning in science, and in facilitating well-being and meaning. Feelings of wonder and awe through science have been found to promote interest in learning in science (McPhetres, 2019). Likewise meaningful engagement and spiritual experiences in science could improve learning and retention, and could also predict better long-term educational outcomes and success in science. Spirituality of science might also hold implications for overall happiness and well-being. It has been observed that religious people are generally happier and fare better on life satisfaction measures than non-believers (Diener, Tay & Myers, 2011, Koenig & Larson, 2001; Ritter, Preston, & Hernandez, 2014), arguably because religion provides a source of

meaning (Steger & Frazier, 2005) which helps buffer stress (Inzlicht, Tullett, & Good, 2011) and feelings of helplessness in the face of uncertain events (Valdesolo & Graham, 2014). Such findings could imply that non-religious people are at a relative disadvantage compared to their religious counterparts and may suffer from lower emotional and psychological functioning from lack of religious meaning. But other research suggests the relationship between religion and mental health is curvilinear, with high positive well-being indicated for both strongly religious and non-religious people (Galen & Kloet, 2011). If science serves a source of spirituality one important implication is it may provide similar benefits for psychological well-being, even for non-religious people.

The Present Research

The present work examines the *spirituality of science*, defined as the experience of meaning, transcendence, and connection derived from scientific ideas, theories, and scientific process. The potential spiritual component of science has been overlooked in psychological studies of science attitudes, where the literature has focused more on topics such as scientific understanding (e.g., Shtulman & Walker, 2020; Lombrozo, Thanukos, & Weisberg, 2008), and trust in science (Rutjens & Sutton, 2018; Fiske, & Dupree, 2014). But examining the spiritual functions of science to include emotional and meaningful components also deserves empirical attention and may have important implications for science learning and well-being.

We developed a short Spirituality of Science scale (SoS) to measure individual differences in spiritual experiences with science, informed by the psychological literature on spirituality (Hill et al., 2000; Piedmont, 1999). Study 1 establishes reliability and validity of this measure in by comparing it to related science attitudes and to experiences with awe and general spirituality. Subsequent studies use the SoS scale to examine benefits of spirituality

of science as source of meaning in non-religious individuals (Study 2) and its implications for science learning (Study 3).

Study 1: What is Spirituality of Science?

The goal of Study 1 was to establish spirituality of science as a construct and introduce the Spirituality of Science (SoS) scale. Individual differences on the Spirituality of Science scale were compared to measures of *Interest in Science* (Johnson et al., 2019) and *Belief in Science* (Farias et al., 2013), to demonstrate convergent validity with other science attitudes. We also establish divergent validity by comparing SoS with these science attitudes on other measures relevant to spirituality: awe, and spiritual transcendence. SoS is expected to be positively related to the *Spiritual Transcendence Scale* (Piedmont, 1999), and *Dispositional Awe* scale (Shiota et al., 2007), as a central affective component of general spirituality, while other science measures have no predicted relationship with these variables. We also include measures of *Intellectual Humility* (IH: Davis et al., 2015), and *Need for Cognitive Closure*, (Webster & Kruglanski, 1994) to assess a general open vs. closed attitude towards new ideas. Intellectual openness should be positively related to science attitudes, including SoS, as the scientific method relies on adaptation to new information, an important scientific value.

Method

Note on all studies. Data, coding, and analyses for all studies (including pilot data and filedrawer studies) can be found at:

https://osf.io/jxqzd/?view_only=d86446fbfb4c48048958f0910445c7e3. For online studies using paid platforms we set a value $N= 500$ participants to maximize power (with 90% power to detect a small correlation $r = .15$). In Study 3 using an undergraduate subject pool we

aimed to collect as many participants as possible, with a minimum of $N = 165$ (90% power to detect a medium correlation $r = .25$).

Participants. 500 participants (287 men, 212 women, 1 non-reporting, $M_{age} = 36.8$ years) were recruited on Amazon Mturk in exchange for a small payment.

Measures. Participants were recruited to participate in a study on attitudes. Unless otherwise stated, all scale items were on 7-point Likert scales, with endpoints: 1 = Strongly disagree; 7 = Strongly agree. Participants completed eight scales, in the order as described below, then completed demographic information.

General Religiosity ($\alpha = .97$), is a 7-item scale to measure strength of religiosity (e.g., “My religious beliefs are very important to me”).

Spiritual Transcendence ($\alpha = .92$) is a 12-item scale to assess general spiritual experiences and attitudes, and emphasizes feelings of transcendence (e.g., “I believe that on some level my life is intimately tied to all of humankind”), adapted from Piedmont (1999) and edited for brevity and clarity.

Interest in Science ($\alpha = .79$) is a five-item scale to measure general interest in scientific topics (e.g., “It is important to me to spend time thinking about scientific topics”), adapted from Johnson et al. (2016). See all items in Table 2.

Belief in Science (BIS; $\alpha = .90$) is a 5-item measure of the degree of trust an individual places in science. This scale was based on the scale from Farias and colleagues (2013). But, where some items in the original scale pitted science and religion against each other, for our purposes we instead focus exclusively on endorsement of science as a way of knowing, (e.g., “We should only rationally believe what is scientifically provable”). See adapted scale in Table 2.

Spirituality of Science (SoS; $\alpha = .93$), is a 10-item measure of transcendent emotion, meaning, and connection through science, (e.g., “Science reveals the beauty of the world we

live in”) developed by the first author. Development of the scale was informed by the psychological literature on spirituality (Hill et al., 2000; Pargament, 1999; Zinnbauer et al., 1997), and drew on themes from the Spiritual Transcendence scale (STS; Piedmont, 1999) which measures general spirituality through three central themes of: 1) transcendent emotion from spiritual activity, 2) belief in the unity and purpose of life, and 3) sense of connection and responsibility to others. This informed our own conceptualisation of spirituality of science, and the SoS scale similarly assessed the spiritual relationship to science along three themes of emotional elevation (e.g., “*thinking about science brings me deep joy*”), meaning (e.g., “*there is an order to science that transcends human thinking*”), and connection (e.g., “*all things are connected through science*”). Some items in the Spirituality of Science scale were directly adapted from the Piedmont (1999) scale, by modifying wording to apply to science (e.g., “*I have had at least one peak experience*” on the STS was modified for the SoS to become “*I have had a peak experience while engaged in science*”). Additional items in the scale were written for the scale to support the themes of transcendence, meaning, and connection. See all items in Table 1. Pilot-testing ($N = 64$) revealed the final 10-item scale to have good internal reliability ($\alpha = .83$), see archived data.

Need for Cognitive Closure (NCC; $\alpha = .80$) is a 7-item scale to measure preference for certainty in intellectual situations, adapted from Webster and Kruglanski (1994; e.g., “I dislike questions which could be answered in many different ways”).

Intellectual Humility (IH; $\alpha = .88$) is a 6-item measure of openness to new ideas and understanding limits of one’s own understanding, e.g., “I reconsider (rethink) my opinions when presented with new evidence”, (adapted from Davis et al., 2015).

Awe ($\alpha = .86$) is a 6-item measure of individual differences in daily experiences of awe, e.g., “I feel awe” (Shiota, Keltner & Mossman, 2007).

Results

SoS Scale Statistics. The 10-item Spirituality of Science scale showed strong internal reliability ($\alpha = .93$), and the mean was calculated to create a Spirituality of Science (SoS) score. Factor analysis on the SoS scale using Principal Component Analysis yielded a solution with single factor was extracted, with initial eigenvalues explaining 62.04% variance. Scale statistics are reported in Table 1.

We conducted a second factor analysis to include items from all three science scales (Spirituality of Science; Belief in Science; Interest in Science), to confirm that each of the separate science scales measured distinct constructs. Principal Component Analysis with Varimax rotation yielded a solution with three factors extracted, with eigenvalues explaining 67.04% variance. The three extracted factors aligned with the three science scales (Spirituality, Belief, Interest). See Table 2 for full factor analyses. In both analyses items from the SoS scale emerged as a single factor and were distinct from other science measures.

Science Measures. Bivariate correlations were conducted between means of all measures, see Table 3. For brevity we only discuss the most relevant associations in the text. All three science measures were strongly intercorrelated ($r_s > .52$, $p_s < .001$), indicating convergence for general positive science attitudes.

Religion and Spirituality. General Religiosity was negatively associated with all science attitudes ($r_s > |-.23|$). Spiritual Transcendence (general spirituality) was only negatively correlated with Belief in Science ($r = -.31$, $p < .01$), but had a modest positive correlation with the SoS scale ($r = .11$, $p < .05$), and was not related to Interest in Science. This illustrates an important divergence between SoS and BIS, and furthermore demonstrates Spirituality of Science is distinct from both other science attitudes and spirituality.

Awe. We predicted that general feelings of awe would be related to Spirituality of Science, as awe is a key element involved in spiritual experiences. Dispositional Awe was positively associated with both SoS ($r = .33, p < .001$) and Interest in Science ($r = .23, p < .001$), but not significantly related to Belief in Science. We followed this with a Linear regression to predict dispositional Awe from all science measures entered together. In the model, Awe was positively predicted by SoS ($b = 0.40 [0.29, 0.50], t = 7.60, p < 0.001$), but not Interest in Science ($b = 0.08 [-0.04, 0.19], t = 1.32, p = .19$), and was negatively predicted by Belief in Science, ($b = -0.26 [-0.324 -0.17], t = -5.91, p < 0.001$). This suggests Awe is not associated with science attitudes in general, rather it is uniquely linked to the spiritual experiences of science.

Intellectual Humility and Need for Cognitive Closure. We included Intellectual Humility (IH) and Need for Cognitive Closure (NCC) as we were interested in cognitive openness as a general scientific value, and to compare Spirituality of Science with other science attitudes in a general openness to thinking ideas. Need for Cognitive Closure (NCC) reflects less openness and showed a small negative association with both SoS and Belief in Science. In multiple regression with all science attitudes as predictors, Belief in Science predicted higher NCC: ($b = 0.10 [0.02, 0.18], t = 2.41, p = .016$), Interest in Science predicted lower NCC, ($b = -0.17 [-0.28, 0.07], t = 3.34, p = .001$), and SoS was not a significant predictor ($b = -0.03 [-0.13, 0.07], t < 1$). The correlations with Intellectual Humility (IH) suggest more openness to ideas and was positively related to all science attitudes ($r_s > .31$). In a multiple regression all science attitudes independently predicted Intellectual Humility: SoS ($b = 0.14 [0.04, 0.23], t = 2.87, p = 0.004$), Interest in Science, ($b = 0.20 [0.10, 0.30], t = 3.82, p < .001$), BIS ($b = 0.08 [0.05, 0.16], t = 2.08, p = .04$). Overall, results suggest that cognitive openness is related to general science attitudes, but is not particular to Spirituality of Science, echoing previous findings that spiritual experiences are not related to general cognitive openness (Preston & Shin, 2017).

Summary

Study 1 introduced Spirituality of Science, both as a scale and a general construct. The ten-item SoS scale showed strong internal reliability and items held together as a single factor in factor analyses. As expected, the SoS scale was strongly correlated with other science attitudes including interest in science and belief in science as the best way of knowing. But unlike other science attitudes, the SoS scale showed positive relationships with both dispositional awe and general spirituality. This divergence suggests that SoS reflects a unique attitude toward science that is not captured by general belief or interest in science, and which is characterized by its unique associations with awe and spirituality.

Study 2: Well-being and Meaning in Nonbelievers

If science can serve as a source of spirituality, an interesting implication is that it may provide a source of meaning and general well-being outside of religious spirituality. It is commonly reported that religiosity is associated with better psychological well-being (e.g., Diener, Tay, & Myers, 2011; Park, 2005; Ritter, Preston, & Hernandez, 2014). And a common reason suggested for this is that religion provides a source of existential support not available to non-religious people (Adamczyk, Zarzycka, & Zawada, 2022). But religion is not the only means to meaning, and non-religious people can experience meaning from non-religious sources (Speed, Coleman, & Langston, 2018; Galen, 2018; van Mulukom et al., 2022), including meaning from science (Uzarevic & Coleman, 2021). Study 2 aimed to show that differences in spirituality of science predict well-being and meaning among non-religious people. In a large survey sample of agnostic and atheist respondents, Spirituality of Science was used to predict several measures of well-being: Subjective Happiness (Lyubomirsky & Lepper, 1999), Satisfaction with Life (Diener, Emmons, Larsen, & Griffin, 1985), Meaning

in Life (Steger et al., 2006), and Stress (Cohen et al., 1983), and compared with Belief in Science (Farias et al., 2013) as a way of knowing. It was expected that (unlike Belief in Science) Spirituality of Science would predict stronger meaning in life and psychological well-being.

Method

Participants. 526 participants (232 women, 294 men, $M_{\text{age}} = 34.7$ years) were recruited from Amazon's Turk Prime service for a small payment. We pre-selected participants who identified as atheist or agnostic prior to the study, and those who identified as religious diverted to an unrelated study (on religious belief and environmental attitudes).

Materials and procedure. All measures were presented on 7-point Likert scales as described below and presented in randomized blocks.

Participants completed the 5-item *Belief in Science* scale (*BIS*; $\alpha = .85$) and 10-item *Spirituality of Science* scale (*SoS*; $\alpha = .91$), as in Study 1.

The *Meaning in Life Questionnaire* (*MLQ*) is a 10-item measure asking individuals to reflect about what makes life feel important and significant to them on a 7-point Likert scale, endpoints 1 = "Absolutely Untrue", 7 = "Absolutely True" (Steger et al., 2006). The scale is comprised of two subscales: Search for Meaning in life (*SM*; e.g., "I am looking for something that makes my life meaningful." $\alpha = .97$) and Presence of Meaning in life (*PM*; e.g., "I understand my life's meaning." $\alpha = .96$).

Perceived Stress Scale short form (*PSS-10*; $\alpha = .91$) is a 10-item measure of perceived stress (e.g., "In the last month, how often have you felt nervous and 'stressed'?"), Cohen et al., 1983). Participants respond to statements on a 5-point Likert scale: Never (0), Almost Never (1), Sometimes (2), Fairly Often (3), and Very Often (4).

Satisfaction with Life Scale (SWL; $\alpha = .94$) is a 5-item measure of one's overall life satisfaction (e.g., I am satisfied with my life), answered on a 7-point Likert scale, with endpoints: 1 = "Strongly disagree", 7 = "Strongly agree" (Diener, Emmons, Larsen, & Griffin, 1985).

Subjective Happiness Scale (SHS; $\alpha = .94$) is a 4-item measure of self-reported happiness (Lyubomirsky & Lepper, 1999), answered on a 7-point Likert scale, (e.g., Compared to most of my peers, I consider myself: [1] less happy to more happy [7]).

Finally, participants reported agreement on 1-7 Likert scales for three belief items: "*I believe in God*"; "*I consider myself a religious person*", and "*I consider myself a spiritual person*".

Results and Discussion

All Scale statistics and bivariate correlations are reported in Table 4.

Science and Religion measures. As in Study 1, the SoS scale was strongly correlated with Belief in Science ($r = .40, p < .001$). We purposely selected for non-religious participants, and means for self-reported belief in God ($M = 1.55, SD = 1.13$), religiousness ($M = 1.17, SD = .58$), and general spirituality ($M = 2.03, SD = 1.61$) were all near floor. Given the restricted variance in these beliefs, these correlations should be interpreted with caution. But we note that Belief in Science was negatively correlated with all three measures of belief in God ($r = -.31, p < .001$), religiosity ($r = -.24, p < .001$), and general spirituality ($r = -.20, p < .001$), whereas SoS was positively correlated with self-reported spirituality ($r = .12, p = .007$), but had no significant relation to either belief in God or religiosity.

SoS and well-being. As expected, BIS and SoS diverged in their associations on the well-being measures. Spirituality of Science was positively related to almost all well-being measures, including Subjective Happiness (SHS; $r = .31, p < .001$), Satisfaction with Life (SWL; $r = .26, p < .001$), Search for Meaning (SM; $r = .19, p < .001$), and Presence of

Meaning (PM; $r = .29, p < .001$), see Table 4. Notably, SoS was associated with both Search for Meaning and Presence of Meaning, though these variables were negatively related to each other (if one already feels the presence of meaning, the search for meaning is less important). But for those higher in SoS, both facets of meaning are high, suggesting that the search for meaning persists despite already having experiences of meaning. Belief in Science, in contrast, was unrelated to most well-being measures, and only showed a small relationship with Presence of Meaning ($r = .11, p = .011$), and a small negative relationship with Stress ($r = -.13, p = .003$).

Because both SoS and BIS predicted variance in Presence of Meaning (PM), multiple linear regression was used to predict PM with both SoS and BIS entered together. SoS remained significant in the regression model but BIS was not, see Table 5.

Summary

In a large survey of atheists and agnostics, greater SoS was associated with meaning and well-being measures, including Subjective Happiness, Life Satisfaction, Presence of Meaning, and Search for Meaning. This illustrates an important parallel with religious spirituality in fostering sense of meaning in life, and benefits of spirituality of science may be especially important to non-religious people who do not experience meaning from religious sources. Study 2 showed further evidence for a divergence between SoS and Belief in Science as measures, as the latter did not predict well-being. But more importantly, results illustrate the important psychological benefits of using science as a source of spirituality, above just belief in science.

Study 3: Engagement and Learning in Science

Another potential benefit of spirituality of science is that it may promote better learning of scientific information. We tested this idea in Study 3, where participants read information on either a scientific topic (research on black holes) or non-science related topic (applying for a mortgage), and tested recall of that information. We predicted that individuals high in Spirituality of Science would show stronger engagement with the science material, and in turn this would predict better recall of the scientific information they read

Method

Participants. 171 undergraduate students volunteered to participate in exchange for partial credit in a psychology course, (145 women, 21 men, 4 other, 1 non-disclosing; $M_{\text{age}} = 18.8$ years).

Measures and Procedure. Participants completed an online survey, and all items were scored on 5-point Likert scales. First, participants completed measures of *Belief in Science* (BIS; $\alpha = .76$) and *Spirituality of Science* (SoS; $\alpha = .84$). The SoS scale included all items as in Studies 1 and 2, adding one reverse-scored item: “I don’t feel much meaning in science”. Participants were randomly assigned to read information about either black holes (Science condition) or mortgage applications (Control condition). Information in both conditions was described on three pages, each accompanied by a related image. Participants rated how they felt during the reading on twelve different emotions (*bored, engaged, annoyed, excited, in awe, anxious, interested, confused, upset, happy, scared*). Participants then completed a five-item *Small Self scale* ($\alpha = .66$; Shiota, Keltner, & Mossman, 2007; e.g., “I feel the existence of things greater than myself”). Feelings of small self—where one feels tiny in comparison to something or someone greater than oneself—have been shown to be central to feelings of awe (Piff et al., 2015; Bai et al., 2017) and spiritual experiences (Preston

& Shin, 2017), and so was predicted to correlate with SoS and learning outcomes for science material. Participants next completed a 4-item alternative version of the *Cognitive Reflection Task* (CRT; Thomson & Oppenheimer, 2016) to control for effects of intuitive vs. reflective thinking on learning. Like the original CRT (Frederick, 2005), the alternative CRT is designed to capture a more reflective, rather than intuitive thinking style, (e.g., “If you’re running a race and you pass the person in second place, what place are you in?”). We included the CRT to rule out the possibility that any observed effect of SoS on science learning is explained through general scientific thinking or ability. All participants were then tested for recall of science and mortgage information, with three questions about black holes, and three questions about mortgages, based on information given in the readings. Finally, participants completed demographic information and were debriefed.

Results

Emotion Factors. Factor analysis was conducted on the twelve different emotion responses to the reading, to reveal common emotional themes. Principal components analysis with Varimax rotation was used to extract factors with eigenvalues > 1 . A two-factor solution emerged accounting for 56% of the variance. Factor 1 (Engagement) included loadings $>|.50|$ on seven items: *engaged*, *in awe*, *excited*, *interested*, *happy*, *amused*, and *bored* (negative load). Mean ratings of these responses (reverse-score for *bored*) were calculated into a single variable, dubbed “Engagement” ($\alpha = .87$). Factor 2 included positive loadings $> .50$ on five items: *annoyed*, *upset*, *scared*, *confused*, and *anxious*. Mean ratings of these responses were calculated into a single variable, dubbed “Anxiety” ($\alpha = .71$).

Correlations. Bivariate correlations and scale statistics for all measures are reported in Table 6. As in Studies 1 and 2, means for the SoS and BIS scales were strongly positively correlated ($r = .40, p < .001$). The Engagement emotional factor was positively correlated with

both SoS ($r = .36, p < .001$) and BIS ($r = .16, p = .03$). The Anxiety factor was also correlated to SoS ($r = .17, p = .03$), but was not related to any other variables. The Small Self scale (Shiota et al., 2007) was used to assess feelings of personal smallness, and as predicted, was positively correlated with SoS ($r = .16, p = .037$) and Engagement ($r = .18, p = .022$), but not BIS ($r = .0003, p = .996$). The alternate CRT (Thomson & Oppenheimer, 2016) is comprised of 4 items ($M = 2.64; SD = .97$). This measure was included to differentiate SoS from general intelligence or thinking styles that would facilitate learning. The CRT had a positive relationship with BIS ($r = .20, p = .01$), but was not significantly related to SoS ($r = .14, p = .064$). This supports the idea that the spirituality of science scale is not a measure of intellectual ability but is specific to the experience with science.

Learning. Mean correct responses to the three science (black hole) questions and three mortgage questions were calculated. As expected, more correct responses to black hole questions were given in the Science ($M = 2.47; SD = .83$) vs. Control condition ($M = 1.04; SD = .80; F(1, 170) = 132.01, p < .001; \eta^2 = .44$). Overall, correct responses to the black hole questions positively correlated with SoS ($r = .18, p = .021$), mean Engagement during reading ($r = .53, p < .001$) and feelings Small Self ($r = .19, p = .016$), but not with BIS ($r = .09, p = .25$). As expected, more mortgage questions were answered correctly in the Control condition ($M = 2.40; SD = .69$) vs. Science condition ($M = 1.82; SD = .77; F(1, 170) = 26.99, p < .001; \eta^2 = .14$). Correct answers to mortgage questions were not correlated with SoS ($r = .08, p = .33$), nor any other measures in the study, see Table 6.

Effects of Engagement. SoS, Engagement, and Small Self were each found to be correlated with correct black hole answers. The relative contributions of these variables in predicting correct science answers was examined using linear multiple regression. All variables were entered together in the model. Engagement was a significant predictor, ($b =$

0.64 [0.47, 0.82], $t = 7.72$, $p < 0.001$), but SoS ($b = -0.04$, $t < 1$), and Small Self ($b = 0.16$ [-0.06, 0.37], $t = -1.47$, $p = 0.14$) were not. This is consistent with the idea that people high in SoS may retain more science learning through stronger engagement with the material. We tested whether Engagement mediated the effect of SoS on correct science answers using regression with Sobel test (Sobel, 1982). In Model 1, SoS alone was shown to predict mean Engagement: $b = 0.51$; $SE = .10$, $t = 4.98$ $p < 0.001$. In Model 2, SoS and Engagement were entered together to predict correct black hole answers. Only Engagement was significant in the regression, ($b = 0.660$, $SE = .09$, $t = 7.53$, $p < 0.001$) but SoS did not ($b = -0.02$, $t = -0.18$, $p = .86$). This indicates the effects of SoS on correct science answers could be explained via greater feelings of Engagement among those higher in SoS, and the Sobel test (Soper, 2023) supported full mediation through feelings of Engagement ($z = 4.14$ $p < .001$).

Summary

Study 3 examined the influence of Spirituality of Science on engagement and learning of scientific information. Results provided more convergent and divergent evidence for Spirituality of Science: SoS was correlated with feelings of Small Self, emotional engagement during reading, and Belief in Science, but was not related to analytical thinking. SoS did not predict participants' correct responses to the non-scientific information, did predict correct responses to the science (black hole) information, and this was best explained through feelings of engagement with the science material.

General Discussion

Science helps provide a deep sense of wonder, understanding, and connection, that we argue here can serve as a source of spirituality for some people. Three studies investigated differences in spirituality of science and their relationship to feelings of awe, well-being, meaning, and learning in science. In Study 1, Spirituality of Science (SoS) was related to

other science attitudes, but only Spirituality of Science predicted general spirituality and feelings of awe. In Study 2, Spirituality of Science (but not belief in science) predicted well-being and meaning in a group of atheists and agnostics, suggesting that scientific spirituality can provide similar psychological benefits as does religious spirituality. Study 3 illustrated that individual Spirituality of Science predicts engagement and learning in science. People high in Spirituality of Science (but not belief in science) were more positively engaged when reading information about black holes and later recalled more information they read, but SoS did not predict recall for non-scientific information. Together these studies indicate that science can indeed be a genuine source of spirituality for some individuals, with intellectual and emotional benefits.

Future of Spirituality of Science

The intent of the present research was to establish spirituality of science as an important construct, not just as a measure, but as a way to capture the meaning experienced through science. We believe these studies do well to establish spirituality of science as a phenomenon and to show implications for well-being and learning, and also to distinguish it from other related kinds of scientific thinking and attitudes. But we consider these to be just an introduction to the topic that provides a jumping off point for new lines of research. Studies here on learning outcomes can be extended with longitudinal designs to examine retention and learning outcomes over longer periods. Here we had compared SoS to belief in science as a way of knowing, to differentiate the spiritual aspect of science attitudes from general acceptance of science. But future research could compare SoS to other related science attitudes, such as enjoyment in science or understanding of science. Studies on science and well-being may also be extended with longitudinal and experience sampling methods that could explore the downstream effects of spirituality of science on daily life

satisfaction and meaning in life. Well-being research may also extend to physical health as a parallel to the benefits of religious spirituality on health (Park, 2007), consistent with past research that meaning in life is a central contributor to physical health (e.g., Ryff & Singer, 1998; Nygren et al., 2005; Wong & Fry, 1998). Future research could also compare different kinds of scientific theories, examine what aspects lend themselves to spirituality of science, especially in regards to feelings of transcendence, connection, and meaning.

Research could further examine the implications of spirituality of science as it relates to general spirituality. General spirituality is associated with strong moral concerns and prosociality, e.g., feelings of compassion and values of universality (Einolf, 2013). Prosociality is not an inherent characteristic of spirituality but can increase in spiritual people through greater awareness and connection to others (Piff et al., 2015), and awe (Jiang & Sedikides, 2022). Could differences in spirituality of science also predict moral concerns, would spiritual experiences with science similarly activate prosociality?

Cross-cultural studies could explore the generalizability of spirituality through science where experiences and definitions of science differ culturally. Science is culturally universal, all human groups use observation and data to make inferences about the natural world and to solve the practical problems that affect their lives. In larger industrialized cultures, concepts of science may be strongly linked with technology and “cutting-edge” advances, but in agrarian and tribal cultures concepts of science may be more directly tied to nature as it applies to the practical concerns in daily life. So too might ideas of spirituality of science in these cultures, and cross-cultural research can help to establish different meanings of spirituality of science, and where it might meld into other kinds of spirituality. Western cultures may also be more likely to actively separate practices of science and religion, where in other cultures they are seen as entirely compatible as practices that enrich rather than contradict each other (Rios & Aveyard, 2019; McPhetres, Jong, & Zuckerman, 2021). In this

case, spirituality of science may be common in other cultures as well and could be associated with higher religiosity where science and religion are seen as compatible.

Spirituality by any other name

Our argument that science serves as a source of spirituality may seem a radical or contradictory approach. How can spirituality be derived without belief in God, the supernatural, or some other aspect of the sacred? But we argue (as others have) that spirituality can be independent from any supernatural belief. Rather, we specify spirituality as marked by feelings of meaning, connection, and profound transcendent emotion (e.g., Emmons, 1999; Piedmont, 1999, Saucier & Skrzypińska, 2006). Elements of spirituality can apply to the supernatural and be derived from personal belief in God. But these can also apply to experiences with science and be without any supernatural element.

But we recognize *sacredness* perception as an integral part of spirituality in general, and of spirituality of science. Sacredness itself has been notoriously tricky to define, however the best definitions of sacredness characterize it as some quality of “specialness” to be set apart from ordinary things (Pargament et al., 2017), and characterized by a set of sacred qualities: transcendence, ultimacy (perception of truth), and boundlessness (beyond space and time) (see also Pargament & Mahoney, 2005). These elements overlap with our own operationalization of spirituality in its application to science and are reflected in the items on the SoS scale. Importantly, perceptions of sacredness apply to both a “core” of the divine (e.g., God) and to ordinary things which have taken on qualities of the sacred (Pargament et al., 2017). Sacredness can therefore be extended to science as well as other domains, (e.g., art, personal relationships) providing those experiences are characterized by similar transcendent emotions and sense of connection and purpose. For example, experiences in nature are often cited as a source of spirituality (Preston & Shin, 2017) and the

sacred (Delaney, 2005), as it can evoke these feelings of transcendence and connection to the universe. That said, science possesses some unique attributes which particularly lend itself to experiences of spirituality. Science and religion share a common explanatory function for that lends itself to creating meaning (Preston & Epley, 2005). Other kinds of experiences (like art) might also have transcendent moments of awe or gratitude but may not fulfill existential functions. This does not mean spirituality cannot be found in other domains, only that science may be particularly adept in eliciting the sense of coherence underlying spirituality.

Spirituality of Science and Religion

The idea of spirituality of science should be distinguished from other issues surrounding the relationship between science and religion. Psychology research on the relationship between science and religion has often focused on their roles as different kinds of explanatory systems for understanding the world (Davoodi & Lombrozo, 2022), and the extent that these systems are viewed as competing or complementary (e.g., Preston & Epley, 2009; Legare et al., 2012; for a discussion see Rutjens & Preston, 2020). The idea here is a different approach: that like religion, science can be a source of spirituality. Indeed there is reason to think that there should be a stronger direct connection between science and spirituality than there could be between science and religion. The science-religion relationship tends to focus on external factors such as their roles as explicit belief systems. But science can be directly linked to spirituality through *internal* experiences of meaning and awe. Indeed, if there is any meaningful point of connection between science and religion, it may be through a shared sense of spirituality that they can each evoke.

Further research could help explore the relationship between scientific spirituality and religious spirituality. In these studies we observe a negative correlation between Spirituality of Science and general religiosity. But this does not mean the two forms of spirituality are incompatible with each other. It is certainly possible to experience spirituality through both

science and religion. Religious people can already derive meaning from their religious beliefs, but perhaps using science as an additional source of spirituality could further boost the meaning and well-being in a religious person. But it is alternatively possible that this would be redundant with the meaning provided by religion. However, we suspect the former to be more likely, and that science can be seen as a way of enhancing religious spirituality. Indeed, religious people see less conflict between religion and science (Leicht et al., 2021) one way that science and religion may be seen as compatible is through their common spirituality.

Conclusion

Though science and religion differ in many ways, they share a capacity for spirituality through their deep feelings of awe, coherence, and meaning in life. This capacity for spirituality has some important benefits and implications, as we find here. People with greater feelings of Spirituality of Science were more positively engaged with science material, which predicted recall for science information. And in a group of atheists and agnostics, Spirituality of Science predicted measures of well-being and meaning in life, paralleling the positive effects of religion that is frequently observed in religious people. This work contributes not only to our current understanding of science attitudes, but also to our understanding of spirituality.

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