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Nature of Science Views and Epistemological Views of College Biology Students

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Abstract Epistemological views characterise how individuals view the certainty, source and organization of knowledge. Previous research has demonstrated some relationships between epistemological views and nature of science (NOS) views. These relationships may be particularly interesting for biology students who are learning about topics such as evolution which are societally controversial but not scientifically controversial. In this study, we examine the relationship between epistemological views and empirical NOS views for three classes of college biology learners in a Midwestern US university. We used the Learning Contexts Questionnaire to characterise participants' epistemological Perry levels and question 1 of the VNOS-C to characterise their empirical NOS views. Based on a series of chi-square analyses, no relationship between Perry level and empirical NOS views was identified. Significant relationships between empirical NOS views and gender and empirical NOS views and biology class were identified. These findings and implications for future work are discussed.

Résumé Les conceptions épistémologiques caractérisent les façons dont les personnes conçoivent le degré de certitude, la source et l'organisation des connaissances. Les recherches antérieures ont montré l'existence de certains liens entre les vues épistémologiques et les vues sur la nature des sciences. Ces liens peuvent être particulièrement intéressants pour les étudiants de biologie dont l'apprentissage comprend des sujets tels que l'évolution, qui sont controversés sur le plan sociétal, mais ne sont pas controversés sur le plan scientifique. Dans cette étude, nous analysons les liens entre les points de vue épistémologiques et les points de vue empiriques sur la nature des sciences dans trois classes de biologie au niveau collégial. Nous avons utilisé le Questionnaire sur les contextes d'apprentissage pour déterminer le niveau épistémologique des participants selon le modèle de Perry, et la Question 1 du VNOS-C pour définir leurs points de vue empiriques sur la nature des sciences. Sur la base d'une série d'analyses χ^2 nous n'avons relevé aucun lien entre le niveau de Perry et les points de vue empiriques sur la nature des sciences. Des liens significatifs ont été relevés d'une part entre les points de vue empiriques sur la nature des sciences et le sexe des participants,

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et d'autre part entre ces points de vue et la classe de biologie. Ces résultats et leurs implications pour des recherches ultérieures sont analysés.

Keywords Biology education · Epistemology · Gender differences · Nature of science

Empirical Nature of Science Views and Epistemological Views of College Biology Students

Although wide consensus exists within the scientific community, biology learners often reject societally denied science like evolution and climate change because of insufficient evidence (Dagher & BouJaoude, 2005). Often, this rejection is connected to learners' deep commitment to a conflicting religious worldview (Blackquiere & Hoese, 2016). In this regard, seemingly no amount of empirical evidence could effectively be used to supplant a pre-existing conclusion. For some biology learners, this rejection represents a misappropriation of the concept of scientific skepticism and a misunderstanding of consensus views of the empirical nature of science (NOS) as understood within the science education community (Akyol, et al., 2012; Kim & Nehm, 2011; Partin, et al., 2013). From a science learning perspective, these learners misunderstand that scientific knowledge is based upon multiple lines of evidence and are subject to change with additional lines of or reinterpretation of evidence. From a wider epistemological perspective, these learners expect knowledge to be certain, unchanging and consistent with authorities such as religious dogma.

Previous literature has connected evolution rejection to both inadequate empirical NOS views (Dagher & BouJaoude, 2005) and less epistemological sophistication (Borgerding, Deniz & Shevock, 2017; Sinatra, et al., 2003). In this study, we directly examine empirical NOS views and epistemological sophistication of college biology learners in an effort to suggest pedagogical interventions that embed NOS and general epistemological scaffolds into biology learning. Specifically, we address the following research questions: (RQ1) To what extent, if at all, are epistemological views and empirical NOS views related for biology learners according to a reduced version of the written VNOS? (RQ2) How do empirical NOS views differ across three biology classes, by gender, and by year in school? And (RQ3) How do college biology learners connect societally denied science (evolution) to their empirical NOS and epistemological views?

Epistemological Views and NOS

Epistemology is a philosophical endeavour focused on "the origin, nature, limits, methods, and justification of human knowledge" (Hofer, 2002, p.4). Schommer (1994) characterised epistemological views as one's positions on the "source, certainty, and organization of knowledge" (p. 293). Science educators are interested in epistemological beliefs to illuminate how students develop their views of knowledge. Hewson (1985) described epistemological beliefs as "the standards which a person holds which he or she used to judge knowledge" (p.164). These standards may be particularly interesting for biology students who are learning about topics such as evolution which are societally controversial but not scientifically controversial.

Perry (1970) and his colleagues were the first to define epistemological beliefs and classify college students' epistemological beliefs. Perry's (1970) model was developmental in nature and assumed that there was a continuum from low-level epistemological beliefs to sophisticated epistemological beliefs. Moore (2002) combined some of Perry's (1970) adjacent nine stages together culminating in a four-stage model including positions of duality, multiplicity, relativism and commitment to relativism (dialectical).

More recent studies also support the developmental nature of epistemological beliefs by pointing out the relationship between epistemological sophistication and educational level. Lonka and Lindblom-Ylanne (1996) found that advanced psychology and medical students were more relativistic than freshmen in their respective fields. Similarly, Mason et al. (2006) reported that thirteenth graders demonstrated less absolutist views than eighth graders. In addition to the number of schooling years, it was found that type of school curriculum might have an impact on students' epistemological beliefs (Mason et al., 2006; Wang, Zhou & Shen, 2016). Mason et al. (2006) also found that boys reflected more absolutist views than girls in a study with a sample size of 881 including students at fifth, eighth, eleventh and thirteenth grades.

In science, relinquishing the concept of a single absolute truth and accepting that conflicting claims might have some validity are particularly difficult for students because they tend to believe that scientific knowledge is static and given to them by scientists (Mason et al., 2006; Bromme, Kienhues & Porsch, 2010; Muis & Foy, 2010). For this reason, it is natural for most science educators to notice the similarities between epistemological beliefs and NOS. While epistemological beliefs address ideas about the nature and justification of knowledge generally, one's NOS views more specifically encapsulate the epistemology of science or the values and beliefs inherent to the development of scientific knowledge (Lederman, 1992). Important NOS tenets include that scientific knowledge is reliable but tentative, is empirically based but not through a singular scientific method, results in theories (explanations) and laws (relationships), and is the product of human subjectivity, creativity, and the social-cultural context in which it is produced (National Science Teachers Association, 2000).

The teaching and learning of NOS have been found to be connected to epistemological views (Akerson & Buzzelli, 2007; Akerson et al., 2006; Deniz, 2011). For instance, students at the dualism stage according to Perry's (1970) epistemological development model are more likely to think that scientific knowledge is not tentative, scientists are not creative or subjective and scientific knowledge is not inferential (Akerson & Buzzelli, 2007; Akerson et al., 2006). Epistemological development was also found to be connected to the ability to learn and retain more sophisticated NOS views. For example, Abd-El-Khalick and Akerson (2004) found that holding right versus wrong dualistic epistemological beliefs interfered with acquiring informed NOS views. Similarly, Akerson et al. (2006) found that preservice teachers at higher stages of Perry's epistemological development model were better able to improve and retain their informed NOS views.

Unlike Perry' (1970) unidimensional developmental epistemological beliefs model, Hofer and Pintrich (1997) conceptualised epistemological beliefs as a multidimensional construct and suggested that two overarching dimensions (nature of knowledge and nature of knowing) with four sub-dimensions can capture peoples' epistemological beliefs. In this conceptualization, the nature of knowledge includes two sub-dimensions: certainty of knowledge (e.g., truth is unchanging in science) and simplicity of knowledge (e.g., knowledge is simple). Younger students usually hold naive beliefs about the nature of knowledge. That is, they believe knowledge is certain and unambiguous. As they grow older and develop, they start to adopt a more sophisticated view of knowledge and believe knowledge to be changing (tentative NOS). The nature of knowing dimension includes a source of knowledge sub-dimension. Beliefs about the source of knowing refer to viewing knowledge as either residing in external authorities such as scientists or teachers or as created within the student. Another sub-dimension for the nature of knowing is the justification for knowing sub-dimension. Justification for knowing includes how people evaluate knowledge claims in light of evidence and experts' knowledge and opinion (Hofer & Pintrich, 1997). Later, Hofer (1997) developed an epistemological beliefs instrument based on this conceptualization. In addition to the original four sub-dimensions, this instrument included a new sub-dimension, the attainability of truth (e.g., scientists can ultimately get to truth).

Using Hofer's multidimensional approach to epistemological development, Deniz (2011) drew attention to the relationship between certain dimensions of Hofer's (1997) epistemological beliefs dimensions and some NOS aspects. For instance, Deniz (2011) stated that there is a clear conceptual similarity between the certainty of knowledge sub-dimension and the tentative NOS aspect. Naïve beliefs about the certainty of knowledge dimension include viewing scientific knowledge as either a right/wrong unchanging subject as opposed to changing over time in light of new evidence. For this reason, this certainty of knowledge dimension is similar to the tentative NOS aspect. Deniz (2011) also pointed out that a similar conceptual similarity exists between attainability of truth sub-dimension in Hofer's model and the subjective NOS aspect. The attainability of truth dimension addresses the extent to which students think that scientists can ultimately get to the truth. Therefore, it is possible that students who think that attainability of absolute truth is not possible in science are more likely to think that scientific knowledge is subjective because of theoretical and personal biases of scientists.

In addition to these conceptual connections, Deniz (2011) found that explicit-reflective NOS instruction improved preservice elementary teachers' epistemological beliefs as measured by Hofer's (1997) epistemological beliefs instrument. Ozgelen (2012) also found that similar explicit-reflective NOS instruction improved preservice science teachers' epistemological beliefs about science as measured by Hofer's (1997) multidimensional instrument.

Epistemological Development, NOS and Biology Learners

Epistemological development and NOS views may be particularly important for understanding how science learners approach seemingly controversial science content. Borgerding and Dagistan (2018) defined societally denied science as widely accepted within the scientific community but controversial with certain groups in larger society. These societally denied science topics include evolution, climate change, that HIV is the cause of AIDS, the existence of holes in the ozone layer, the rise in antibiotic resistance, health risks caused by cigarette smoking, exaggeration and denial of harmful side effects of pesticides, water and environmental damage caused by hydraulic fracturing, and dangers associated with vaccinations (Liu, 2012). As can be seen, many of these topics are clearly embedded within the biology curriculum, and an understanding of biology learners' epistemological and NOS views in relation to these topics is imperative for developing appropriate curricula regarding these societally denied science topics.

Epistemological and NOS views have been investigated within the context of some societally denied science topics. Most of this literature pertains to the teaching and learning of biological evolution, but more recent literature addresses climate change education as well. Below, we describe some of the empirical findings that connect epistemology, NOS and these topics.

With respect to evolution, the previous literature connecting evolution acceptance to either epistemological views or NOS views has been robust. In terms of NOS, several studies have identified positive relationships between sophistication in NOS understandings and evolution acceptance for college students and science teachers (Akyol et al., 2012; Kim & Nehm, 2011; Partin, et al., 2013). When careful NOS instruction has been embedded within evolution instruction and evolution professional development, learners have improved their NOS sophistication and increased their evolution acceptance (Cofré et al., 2017; Cofré et al., 2018). Yet, evolution rejecters cite conflicting evolutionary evidence (Downie & Barron, 2000); lack of evolutionary evidence (Downie & Barron, 2000; Dagher & BouJaoude, 2005); ideas that evolution is "just a theory" (Dagher & BouJaoude, 2005); and concerns that evolution does not allow experimentation, use of "the scientific method"; and testable predictions (Dagher & BouJaoude, 2005) as reasons for their rejection. Similarly, previous work has connected college biology students' evolution acceptance with their epistemological views. Sinatra et al., (2003) found that college students' epistemological sophistication was correlated with their acceptance of human evolution but not animal evolution. When Deniz, Donnelly and Yilmaz (2008) investigated this relationship with a Turkish sample of preservice biology teachers, no such relationship was found, but the authors cautioned that their epistemological beliefs scale had poor reliability. Using a different epistemological beliefs instrument aligned to Perry's framework, Borgerding et al. (2017) identified several connections between Perry level epistemological classification and views of evolution among college biology students. Specifically, people at Perry's dualism and multiplicity stages more often appealed to authorities for their evolution positions, were less accepting of evolution, less often viewed evolution as an example of "good" science. Perry level dualists, in particular, less often recognized the tentativeness of all scientific knowledge, often indicating that only evolution had "gaps". These findings suggest that biology learners view evolution differently based on epistemological perspectives that differ in terms of the source (authority), justification (what counts as "good science), and certainty (tentativeness) of science.

Recent literature has also explored the relationships between epistemological views, NOS views and climate change. In terms of NOS, climate change instruction has been shown to improve college students'

NOS views (Matkins & Bell, 2007; Clary & Wandersee, 2012) and specifically their views of the evidence for climate change, consensus of scientists and awareness of sociopolitical influences (Lambert & Bleicher, 2013). In terms of epistemological views, Bråten et al. (2009) examined college students' domain-specific epistemological views for climate change and identified four distinct epistemological factors: certainty of knowledge about climate change, simplicity of knowledge about climate change, justification of knowledge about climate change and source of knowledge about climate change. They identified cultural differences regarding these factors in that Spanish college students' parsed certainty of knowledge about climate change into ambiguity and tentativeness while simplicity of knowledge was only identified among Norwegian students (Bråten et al., 2009). Intolerance of ambiguity in the form a need for closure regarding climate change has also been negatively related to plausibility perceptions about climate change among teachers and college students (Lombardi & Sinatra, 2013). Furthermore, the trustworthiness of the knowledge source and message certainty are important predictors of college students' views of the plausibility of anthropogenic climate change (Lombardi, Seyranian & Sinatra, 2014). When climate change has been used to teach about scientific models, Italian secondary students showed gains in their epistemological views with respect to knowledge complexity and a less rigid view of scientific truth (Tasquier et al., 2016).

Demographic variables may be important for the interconnections between epistemology, NOS and acceptance/rejection of societally denied science. For example, not surprisingly, a year in college has been associated with higher Perry levels (Borgerding et al., 2017). Furthermore, science majors have been found to be more accepting of evolution than their non-major peers (Borgerding et al., 2017; Partin et al., 2013). For that matter, science majors have also been shown to have more sophisticated NOS views than their non-major peers (Partin, et al., 2013). Gender has also been shown to be related to evolution acceptance as Korean female teachers were more rejecting than their male counterparts (Kim & Nehm, 2011). Given these findings, demographic variables were included in the research questions guiding this study.

Given these connections between epistemological views and NOS views and the importance of biological societally denied science, we sought to directly investigate NOS views and epistemological views for three classes of college biology students: upper-class majors, introductory majors and non-majors across multiple years in college. One of the primary reasons for evolution rejection is a perception of insufficient empirical evidence, so we chose to focus on the empirical aspect of nature of science in this investigation. Given the importance of demographic identifiers (year in college, gender and type of biology course) deemed important from previous work (Borgerding et al., 2017; Kim & Nehm, 2011; Partin et al., 2013), we also compared empirical NOS ratings among these sub-groups. Specifically, the following research questions guided this study:

(RQ1) To what extent, if at all, are epistemological views and empirical NOS views related to biology learners according to a reduced version of the written VNOS?
(RQ2) How do empirical NOS views differ across three biology classes, by gender, and by year in school?
(RQ3) How do college biology learners connect societally-denied science (evolution) to their empirical NOS and epistemological views?

Methods

This study employed a concurrent mixed methods approach (Creswell & Plano Clark, 2011) entailing the collection of quantitative epistemology data and qualitative (written) empirical NOS data as part of a larger project addressing college biology learners' epistemology connected to evolution. The qualitative empirical NOS data was quantised (Maxwell, 2010; Sandelowski, Voils & Knafl, 2009) in order to determine the statistical relationship between the two constructs.

Sample

The sample consisted of the same 395 college biology learners who participated in the Borgerding et al. (2017) mixed methods study of evolution acceptance and Perry level epistemological views described above. This original sample included college students (226 female, 148 male, 21 no data) enrolled in three classes: an upper-level Evolution course for majors (79 students), an introductory biology class for majors (164 students), and an introductory biology class for non-majors (152 students). Of this sample who completed the written survey, 241 participants (145 female, 90 male and 6 missing) fully completed both the epistemology survey and the VNOS-C item used to assess the empirical NOS. In terms of year in college, the sample included 77 freshmen, 40 sophomores, 41 juniors, 66 seniors and 12 students who characterised themselves as "other".

These three biology courses were selected because they all addressed evolutionary biology, known to be contentious according to one's NOS views, albeit to varying degrees. *Life on Planet Earth* is a large, lecture-based biology course for non-majors. The course requires no pre-requisites and can serve as one of the central liberal education basic science requirements. *Biological Diversity* is a 4-credit lecture and field course, the first course in biology majors' sequence. *Organic Evolution* is a 4-credit lecture course that requires genetics and at least four credits of other biology courses as prerequisites. Of the 241 participants, 69 were enrolled in *Organic Evolution*, 98 in *Biological Diversity* and 74 in *Life on Planet Earth*.

Data Collection

Surveys were completed during the first week of classes in each respective class. Students' epistemological views were measured quantitatively using the Learning Context Questionnaire (Kelton & Griffith, 1986). The LCQ was developed and validated to ascertain college students' intellectual and ethical development and consists of 26 Likert items. The LCQ has been successfully used in other science education research studies (Akerson & Buzzelli, 2007). This scale employed a six-point Likert scale for responses, and the authors reported a Cronbach's alpha of 0.77 (Kelton & Griffith, 1986). These results were used to classify students according to their Perry position.

Empirical NOS views were ascertained for the survey sample using one question from the VNOS-C, a questionnaire designed to elicit students' views of nature of science (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002). In its entirety, this 10-item questionnaire includes questions related to views of nature of science. Of particular interest to this study was the item that characterises how science is different from other disciplines of inquiry, question #1. Participants answered this question in written form: "What, in your view, is science? What makes science (or a scientific) discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?" One limitation of this study is that, given the large sample size, we did not also interview a subset of the survey respondents using the VNOS-C question 1 as recommended by the VNOS-C developers.

The entire survey was entitled, "Views of Evolution and Learning", and began with 20 Measure of Acceptance of the Theory of Evolution (MATE) (Rutledge & Warden, 1999) items that assessed students' evolution acceptance. Although the MATE findings are not reported here, it is important to clarify that students were answering the LCQ and VNOS questions in the context of their views of evolution. As reported later, students' views of evolution were often connected to their empirical NOS views.

Data Analysis

The quantitative analysis first entailed preparing the survey data for analysis. The LCQ items were reverse-coded when appropriate and scores were summed. Using Kelton and Griffith's (1986) categorization scheme, participants' individual LCQ summed scores were used to place them into Perry level categories:

dualist (0–88), multiplist (89–101), relativist (102–114) and dialectical (115-156). These categories were then used for subsequent contingency chi-square analyses.

All VNOS-C question 1 responses were reviewed and analysed by both researchers independently. The analysis of the VNOS-C was initially guided by the analysis recommendations made by the instrument developers (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002). Lederman, et al. (2002) displayed possible naïve empirical NOS views that emphasised a non-tentative, strictly objective, fact-based science and then illustrated how more informed empirical NOS views recognized the role of observation but also acknowledged subjective abstraction from mere observations. Based on the authors' previous work (Donnelly & Argyle, 2011), we sought to further refine and define this scale. Our previous use of this VNOS question 1 suggested an empirical NOS view even more naïve than that suggested by Lederman et al. (2002) in that some respondents view science as a process without mention of its foundation on observation, evidence, data or "facts". Based on this previous work, the authors developed and refined a 5-point scoring rubric was developed on this basis (shown in Table 1). Both researchers independently coded a subset of transcripts and then met to compare codes. Differences were discussed until consensus was achieved, and additional code notes were used to better delineate codes. This iterative process continued until all question 1 responses were coded, and the authors achieved an initial inter-coder reliability of 72.5%. Any coding differences, more pronounced in early batches of independent coding as the coding scheme was still being refined, were resolved through discussion to achieve a final 100% consensus. These codes represented a linear progression of less to more informed views of the empirical NOS, and these qualitative codes were ultimately quantised to create empirical NOS ratings shown in Table 1.

The quantitative scores from the LCQ and quantised codes from the VNOS-C question 1 were used for subsequent analyses for RQ1 and RQ2. First, descriptive statistics were used to characterise this sample. Then, a chi-square test of independence was used to determine if a relationship existed among the constructs of interest in the research questions. Chi-square tests of independence were chosen because they are used to test for relationships between nominal variables. Although all other assumptions prerequisite to the chi-square analysis were met, the assumption of expected frequencies was not met. To rectify this, the two participants with NOS ratings of "5" were eliminated from this analysis, leaving only four cells (25%) with cell counts less than five. Null hypotheses of no relationship were rejected when $p < .05$.

Based on the findings of the quantitative analyses, the first author returned to the VNOS question 1 transcripts to identify any trends in responses to address RQ1 (relationship between Perry level and empirical NOS views) and RQ3 (connections between views of evolution and empirical NOS/ epistemological views) and to help make sense of the findings. This qualitative analysis entailed two steps. First, to make sense of the quantitative findings, responses were sorted by empirical NOS code, and responses within that category were constantly compared (Glaser & Strauss, 1967) to identify commonalities and dimensions of each of the five codes. Second, to address RQ2 regarding connections between participants' empirical NOS views and their views of evolution, all responses that contained reference to evolution, 25 in total, were identified. The first author coded with respect to how participants characterised the empirical nature of evolutionary knowledge.

Results

We first present descriptive statistics to characterise this study's sample. Next, we present findings pertaining to the study's three guiding research questions regarding (RQ1) relationships between Perry level and empirical NOS ratings, (RQ2) relationships between these empirical NOS ratings and demographic categories and (RQ3) how the empirical NOS and epistemological views are connected to evolution in particular.

Table 1 Scoring rubric used to quantitise VNOS-C question 1 responses

Rating	Code	Code notes	Exemplar
1	Incomprehensible/irrelevant	• Does not make sense or does not address the prompt	• "My view is that God created men but I keep an open mind and view the possibilities of evolution" (P242, male, *Biological Diversity*) • "Natural phenomena. It's fun to know about how things live and where they're from" (P350, female, *Biological Diversity*)
2	Comprehensible but not empirical	• Addresses the prompt but does not include any reference to empirical	• "Science is the best educated guess we have to how the world works" (P53, male, *Organic Evolution*) • "science is more based on the earth and the physical things and how they change" (P453, female, *Life on Planet Earth*)
3	Empirical but not tentative	• Mentions empirical (scientists study, do experiments, gather facts/evidence/data, make observations, etc.) • Indicates non-tentative ("proven", "truth", "absolute", etc.)	• "Science can be tested and proven time and time again. It is also universal. Religion and philosophy vary per person and is not based on fact" (P101, male, *Biological Diversity*) • "Science is actual facts about life that ha[ve] been proven true. It differs from religion or philosophy because those are more widespread beliefs." (P476, female, *Life on Planet Earth*)
4	Empirical with no indication of non-tentative	• Mentions empirical (scientists study, do experiments, gather facts/evidence/data, make observations, etc.) • (may have) Tentative: "never sure", "may change"	• "Science is the study of the natural world. Science is based on research and factual data" (P255, female, *Biological Diversity*) • "the study of how things work. Science actually has facts from experimentation while as religion does not" (P453, female, *Life on Planet Earth*)
5	Empirical with no indication of non-tentative, AND subjective	• Mentions empirical (scientists study, do experiments, gather facts/evidence/data, make observations, etc.) • (may have) Tentative: "never sure," "may change" • Subjective: science influenced by scientists' personal views, how they think, what they value, how they were trained, etc.	• "Science is the study of observations, whether in living or non-living. Science differs from proof, observation, testing, and continually changing views from one theory, to adapting new findings from technology etc.…" (P36, male, *Evolution*)

Descriptive statistics characterise the Perry levels and empirical NOS ratings present within this sample for this 241-student sample. In terms of Perry level, 100 (41.4%) students were at the Perry level of dualistic, 87 (36.1%) at multiplistic, 42 (17.4%) at relativistic and 12 (5.0%) at dialectical levels. When rated for their VNOS question 1 responses, 30 (12.4%) received a 1 (incomprehensible/irrelevant), 27 (11.2%) received a 2 (comprehensible but not empirical), 67 received a 3 (27.8%) (empirical but indicates exclusive objectivity), 115 (47.7%) received a 4 (empirical and no indication of non-tentative) and 2 (0.8%) received a 5 (empirical, no indication of non-tentative and indication of subjectivity).

(RQ1) Relationship Between Perry Level and Empirical NOS Ratings

The null hypothesis associated with RQ1 is that there exists no relationship between Perry level and empirical NOS ratings. Table 2 shows the cross-tabulation of Perry level with empirical NOS ratings and includes a contingency chi-square analysis. Contrary to what was expected based on the literature, we found a non-significant chi-square value ($\chi^2_{(9)} = 5.55$, $p > .05$) indicating that no relationship between empirical NOS rating and Perry level exists.

The qualitative analysis of written responses according to empirical NOS rating generated several findings that may help to contextualise the non-finding for RQ1. Below, these qualitative trends are organized by the five empirical NOS ratings from the Table 1 rubric: incomprehensible/ irrelevant, comprehensible but not empirical, empirical but not tentative, empirical with no indication of non-tentative, and empirical with no indication of non-tentative and subjective.

In total, 30 participants' responses were coded as "Rating 1: incomprehensible/irrelevant". Many participants who were coded as "Rating 1: incomprehensible/irrelevant" rejected the premise of the question—that science is different from religion or philosophy. For example, P295 (female) answered, "only what you work with and study, the overall process is the same". Similarly, P410 (gender unknown) responded, "to me there is no difference because it is based on what you believe. Science is science".

One last group of students whose responses garnered a "Rating 1: incomprehensible/irrelevant" focused on aspects of religion or philosophy in their response without addressing science. For example, P477 (male) wrote, "religion has stronger faith and feelings". Similarly, P549 (female) reacted strongly to religion in her response: "I need facts not theories or stories of some imagined guy. Maybe we don't know how we got here. Maybe we should focus on the things going on today".

Twenty-seven participants' responses were coded as "Rating 2: comprehensible but not empirical". Many of these responses indicated that science offers answers while religion/philosophy pose questions. For example, P40 (male) wrote, "Philosophy asks the questions and science answers them". Some of these responses focused on science offering unbiased "answers" while religion and philosophy present mere opinions. One illustration of this position was offered by P543 (female), "I think science has specific answers to most questions, and philosophy has more to do with opinions and beliefs".

In total, 77 responses were categorised as "Rating 3: empirical but not tentative". A vast majority of these responses made reference to proof or proving. For example, P117 (male) reasoned that "science needs proof and evidence of something while religion is based on belief even though there might be evidence disregarding the fact that of belief". Similarly, P296 (male) explained, "science is a systematic study in which the evidence has to be proven, real data". Some participants whose responses were coded "empirical but not tentative" expected scientific knowledge to achieve "truth". For example, 469 (male) drew on this

Table 2 Chi-square test of independence for Perry level with empirical NOS ratings

Perry level	Empirical NOS ratings				
	1: Incomprehensible/irrelevant	2: Comprehensible but not empirical	3: Empirical but non-tentative	4: Empirical with no indication of non-tentative	Total
Dualist	14 (12.6)*	11 (11.3)	30 (28)	45 (48.1)	100
Multiplist	9 (10.7)	8 (9.6)	26 (23.8)	42 (40.9)	85
Relativist	5 (5.3)	5 (4.7)	10 (11.8)	22 (20.2)	42
Dialectical	2 (1.5)	3 (1.4)	1 (3.4)	6 (5.7)	12
Total	30	27	67	115	239

*Expected counts are in parentheses

notion of truth in his response, “science is the study of how things came about and the facts to prove certain things true or false”.

The vast majority of responses were categorised as “Rating 4: Empirical with no indication of non-tentative”, and a few qualitative trends emerged from the analysis of these responses. The most consistent trend in these responses was the tendency to focus on the testability of science and specifically how religion is not testable. Several respondents indicated that religion is different from science because the former is based on opinion. P71’s response illustrates this reliance of religion on opinions: “Religion and philosophy [are] much more open to opinions and beliefs. Science has more facts”. Many participants indicated that, unlike science, religious assertions must conform to a predetermined “dogma” (P352, female) that necessarily makes it “static” (P27, female).

The defining quality of this group that separated it from the Rating 3 category was the lack of reference to certainty. Interestingly, the average number of words for Rating 4 responses (22.4 words, SD = 13.1) was slightly less than that of the Rating 3 responses (22.4 words, SD = 13.3).

Given that there were only two Rating 5 responses, further qualitative examination was not conducted.

(RQ2) Relationship Between Empirical NOS Ratings with Demographic Categories

The second research question examined the extent to which empirical NOS ratings were related to demographic variables such as class (Life on Planet Earth, Biodiversity or Evolution), gender, and year in college. When these chi-square analyses were done comparing NOS rating to class, gender and year in school, the only year in school was not significant. By class (Table 3), NOS ratings were significantly higher for participants in the *Organic Evolution* course and lower for participants in the *Life on Planet Earth* course than expected with a ($\chi^2_{(6)} = 12.19$, $p = 0.05$). Similarly, by gender (Table 4), NOS ratings were significantly higher for females and lower for males than expected with a ($\chi^2_{(3)} = 13.35$, $p = 0.004$).

(RQ3) Connections Between Empirical NOS Views, Epistemology and Evolution

Twenty-two of the 241 (9.1%) participants specifically referenced evolution within their VNOS question 1 responses. The majority (nine) of these evolution-referencing participants were given an empirical NOS Rating 1, and the remaining included two coded as Rating 2, one Rating 3, nine Rating 4 and one Rating 5. The qualitative analysis of these evolution-referencing responses generated several trends connected to both NOS and epistemology.

Several participants made use of the epistemological concept of ambiguity in their responses. Most often, they framed this personally in terms of an openness to alternatives. P242 (male) illustrated this tolerance of ambiguity in his response, “my view is that God created men but I keep an open mind and view the possibilities of evolution”. Others tolerated ambiguity by maintaining the plausibility of evolution. For example, P414 (male) asserted that, “evolution is a hundred percent possible, [I] don’t want to elaborate because people have their own religious beliefs”. Some indicated that they were tolerating ambiguity because of their lack of previous engagement as illustrated by P349 (female) writing, “I don’t have much of a view of evolution. I feel as though I have not studied research enough about evolution to have an opinion”.

Two participants directly referenced authorities as they described the nature of evolutionary knowledge. Both of these referenced the Bible as a religious source of knowledge that likely conflicts with evolution. P277 (female) stated, “I think evolution might be possible but also believe the Bible”. Similarly, P312 (female) wrote, “Even as a strong Christian, [I] believe also in the supporting facts of evolution and do not believe they go against the Bible”.

Several participants referenced the empirical NOS as it pertains to evolution. For example, P93 (female) defined science as the “formation of life through interactions of elements and energy” through “the use of proven methods to explain or support a theory”. Similarly, P115 (male) stated that “there is actually data and research that can show how the earth and organisms were created through evolutionary process”.

Table 3 Chi-square test of independence for empirical NOS ratings and class

Empirical NOS rating	Class			
	Organic evolution	Biodiversity	Life on Planet Earth	Total
1: Incomprehensible/irrelevant	2 (8.4)*	14 (12.3)	14 (9.3)	30
2: Comprehensible, but not empirical	5 (7.6)	13 (11.1)	9 (8.4)	27
3: Empirical but not tentative	21 (18.8)	24 (27.5)	22 (20.7)	67
4: Empirical, no indication of non-tentative	39 (32.2)	47 (47.2)	29 (35.6)	115
Total	67	98	74	239

*Expected counts are in parentheses

A few participants also referenced the tentative NOS and subjective NOS as they characterised evolutionary knowledge. P257 (female) referenced the tentativeness of science in that "Science is different from religion and philosophy because although we observe organisms and our world, we really have no definite answer to how they came".

Discussion and Implications

Contrary to what was expected, no significant relationship between Perry level and NOS ratings was identified. A number of possible explanations may account for this non-finding. First, it is possible that no relationship really does exist between Perry level and NOS views in this sample. In this way, views of the development of scientific knowledge may not be considered as a subset of one's larger views of the development of knowledge more broadly.

Alternatively, the instruments/rating scales used in this study may not have been sensitive enough to identify such a relationship. Our study differs from the previous literature upon which we based our prediction that a significant relationship would be found in that unlike Akerson et al. (2008), we only used the first question of the VNOS-C rather than the entire VNOS. The first question especially targets the empirical nature of science, but students in our sample may have under-represented their tentative views of science when they defined science, as prompted in this question. The qualitative analyses of Rating 1 responses revealed a tendency to reject the premise of the question that science differs from religion/ philosophy or to only address religion in student responses. Inclusion of the full sequence of VNOS questions would have given additional opportunities for students to convey their empirical NOS views. Further investigations are warranted to test this further.

Table 4 Chi-square test of independence for empirical NOS ratings and gender

Empirical NOS rating	Gender		
	Female	Male	Total
1: Incomprehensible/irrelevant	10 (17.9)*	19 (11.1)	29
2: Comprehensible, but not empirical	16 (16.1)	10 (9.9)	26
3: Empirical but not tentative	38 (40.2)	27 (24.8)	65
4: Empirical, no indication of non-tentative	80 (69.8)	33 (43.2)	113
Total	144	89	233

*Expected counts are in parentheses

Another alternative explanation for why no relationship was found between Perry Level and sophistication of empirical NOS views relates to this study's exclusive focus on just this empirical NOS aspect. Although our empirical rating scale encapsulated both the empirical NOS and some of the tentative NOS, question 1 does not strongly elicit the subjective NOS. This subjective NOS may be a particularly important indicator for the transition between Perry level multiplists who maintain that experts simply do not agree *yet* and relativists who expect all knowledge to be context- and perspective-dependent. In this way, the empirical NOS may not be the most salient NOS aspect associated with Perry level sophistication.

The significant relationship between NOS rating and class may be explained in two ways. First, upper-level biology students have had more exposure to NOS concepts during their undergraduate experiences than the non-majors who were likely fulfilling their requirement for a science course by taking the non-majors *Life on Planet Earth* course. Further longitudinal investigation of science majors' NOS views would determine if this explanation holds promise. A second possibility is that biology majors have a "science identity" that is more aligned with sophisticated NOS views. Students in non-majors classes less often identify themselves as "science people" (Borgerding et al., 2017), and identification with science may include a preference for empirical ways of approaching questions.

Interestingly, a significant gender difference was determined for NOS ratings. Previous studies have identified no NOS gender differences found for Korean science teachers (Kim & Nehm, 2011) and Turkish in-service teachers (Karaman, 2017), and a previous study in the USA indicated that US Caucasian males held more sophisticated views of some NOS aspects than their female counterparts (Arino de la Rubia, Lin & Tsai, 2014). While this study's finding of a gender difference may be an artefact of this sample which included more females than males, the rating scale used in this NOS analysis may have favoured females in some way. In meta-analyses of discourse studies, females were found to use more tentative language than males (Leaper & Robnett, 2011). Interestingly, this tentative language did not necessarily reflect uncertainty or lack of assertiveness but rather inter-personal sensitivity (Leaper & Robnett, 2011). This prevalence of tentative language may have allowed more of this sample's females, to be rated with fours compared than their male counterparts. Given this study's finding and the possibility of a tentative language bias in open-ended NOS assessments, future studies should further explore the role of language in NOS assessments.

The RQ3 analysis of evolution and empirical NOS/epistemological views yielded many connections. In terms of epistemological views, participants conceived of evolutionary knowledge in terms of its perceived ambiguity and apparent contradiction with religious authorities. With respect to empirical NOS views, participants both justified and doubted evolution in terms of their perceptions of its evidentiary support and testability. These findings make apparent the need to explicitly teach about epistemological and NOS concepts in the context of evolution. College biology learners should grapple with science's non-reliance upon authorities, tolerance of ambiguity, evidentiary standards and inherent tentativeness of conclusions.

Some key limitations of this study should be noted as readers assess the utility of these findings. First, as noted above, only question 1 of the VNOS-C was used, and the full instrument would have yielded a more complete synopsis of participants' NOS views. Second, the authors did not use interviews containing question 1 to corroborate the written responses. Third, as described above, the rating rubric may have over-inflated non-tentative responses. Fourth, the sample for this study was drawn from a large Midwestern, predominately Caucasian institution and similar studies conducted in other regions with a more diverse population would likely yield different results.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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