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Beliefs and Attitudes about Science and Mathematics in Pre-Service Elementary Teachers, STEM, and Non-STEM Majors in Undergraduate Physics Courses

Lynnette Michaluk[1] · **Rachel Stoiko**[2] · **Gay Stewart**[2] · **John Stewart**[2]

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Abstract Elementary teachers often hold inaccurate beliefs about the Nature of Science (NoS) and have negative attitudes toward science and mathematics. Using a pre-post design, the current study examined beliefs about the NoS, attitudes toward science and mathematics, and beliefs about the teaching of mathematics and science in a large sample study ($N = 343$) of pre-service teachers receiving a curriculum-wide intervention to improve these factors in comparison with Science, Technology, Engineering, and Mathematics (STEM) and non-STEM majors in other physics courses ($N = 6697$) who did not receive the intervention, over a 10-year period. Pre-service teachers evidenced initially more negative attitudes about mathematics and science than STEM majors and slightly more positive attitudes than non-STEM majors. Their attitudes toward mathematics and science and beliefs about the NoS were more similar to non-STEM than STEM majors. Pre-service teachers initially evidenced more positive beliefs about the teaching of mathematics and science, and their beliefs even increased slightly over the course of the semester, while these beliefs in other groups remained the same. Beliefs about the NoS and the teaching of mathematics and science were significantly negatively correlated for STEM and non-STEM majors, but were not significantly correlated for pre-service teachers. Beliefs about the NoS and attitudes toward mathematics and science were significantly positively correlated for both pre-service teachers and STEM students pursing the most mathematically demanding STEM majors. Attitudes toward science and mathematics were significantly positively correlated with accurate beliefs about the teaching of mathematics and science for all student groups.

Keywords Nature of Science · Attitudes toward math and science · Pre-service teachers · STEM and non-STEM undergraduates · Enhanced curriculum

✉ Lynnette Michaluk
lynnette.michaluk@mail.wvu.edu

Rachel Stoiko
rstoiko@mix.wvu.edu

Gay Stewart
gbstewart@mail.wvu.edu

John Stewart
jcstewart1@mail.wvu.edu

[1] Center for Excellence in STEM Education, West Virginia University, Morgantown, WV 26506, USA

[2] Department of Physics and Astronomy, West Virginia University, Morgantown, WV 26506, USA

Introduction

Although controversy exists among philosophers of science and other experts regarding details about the Nature of Science (NoS) (Abd-El-Khalick and Lederman 2000; McComas et al. 1998; Smith et al. 1997), the phrase is used to distinguish a scientific way of knowing from other ways of knowing through "the use of empirical standards, logical arguments, and skepticism" (National Research Council 1996). In the late 1980s, the focus of science education reform centered on the NoS (American Association for the Advancement of Science 1989). Since that time, students' understanding of the NoS has been identified as central to scientific literacy (American Association for the Advancement of Science 1993, 2001; National Research Council 1996), and standards appeared for students' understanding of the NoS (McComas et al. 2009; McComas and Olson 1998). While students' ideas regarding the NoS are contextual and complex, the problematic conceptions they have regarding the NoS play out in the public's engagement with science (Rudolph 2007). In 2011, the importance of the NoS in understanding the differences, similarities, and relationships between science and engineering were recognized in the Next Generation Science Standards (NRC 2011), and helping students develop an informed understanding of the NoS is a major goal of scientific education (Chang et al. 2010; Kimball 1968; Lederman 1992; Lederman et al. 2002). Without an understanding of the NoS, students often develop an idea that science is "done" and that it is a list of facts to memorize (Akerson et al. 2006). Despite the continued emphasis on the importance of understanding, the NoS from primary through post-secondary school, the NoS is rarely addressed accurately or effectively; science teachers do not plan to teach the NoS as they often do not consider the NoS an important educational objective (Abd-El-Khalick et al. 1998).

Elementary teachers' understandings of the NoS are generally inaccurate (e.g., Abell and Smith 1994; Irez 2006), and in-service and pre-service teachers tend to report negative attitudes about mathematics and science (e.g., Handal 2003; Mulholland and Wallace 1996; Palmer 2002; Riegle-Crumb et al. 2015; Shrigley 1974; Tosun 2000), especially compared with other subjects. In-service and pre-service teachers' beliefs about and understanding of the NoS often differ from experts' conceptions (Abd-El-Khalick et al. 1998; Irez 2006; Lederman 1992; Murcia and Schibeci 1999). In particular, pre-service teachers tend to define science in terms of the discovery of knowledge, with minimal understanding of features such as the social aspects of science and the limitations of scientific knowledge (Abd-El-Khalick et al. 1998; Abell and Smith 1994). Many studies have found that pre-service teachers have misunderstandings about fundamental scientific concepts (e.g., Atwood and Atwood 1997; Harlen and Holroyd 1997; Rice 2005; Rice and Kaya 2012; Tekkaya et al. 2004; Schoon 1995; Trundle et al. 2002), a deficiency that might be improved by a better understanding of the NoS.

The importance of the affective domain in the learning and teaching of science has long been recognized by science education researchers (e.g., McGinnis et al. 2002; Simpson et al. 1994), and studies of the general population have shown that better understanding of science is associated with liking science more (Allum et al. 2008; Gauchat 2008; Miller 2004). Simpson et al. defined attitudes toward science as specific feelings which indicate whether a person "likes or dislikes science" (1994, p. 213). Other researchers agree with this view, stating that attitudes toward science capture individuals' subjective beliefs and feelings and includes the value they place on science and their enjoyment of science (reviewed in Haladyna and Shaughnessy 1982; van Aalderen-Smeets et al. 2012). In the current study, McKeon's (1994) position, termed "resolution," is adopted and focuses on nuanced questions (Clough 2007, 2011a) that students should consider in the context of the work of authentic science, scientists (Clough 2011b), and public engagement with science (Allchin 2011; Herman et al. 2013; Mitchell 2009).

Students' attitudes are important predictors of university science course performance (Hazari et al. 2007; Sadler and Tai 2001) and have implications for students' academic development and future careers, as well as their ability to be scientifically informed citizens (Edwords 1986; Hurd 1970; Koballa and Crawley 1985). Beliefs are a separate but related construct, and describe a proposition that is accepted as true by the individual holding the belief (Green 1971; Richardson 1996). Beliefs influence the learning and teaching of mathematics and science (e.g., Otero and Gray 2008; Schoenfeld 1989; Thompson 1992). Researchers have a vested interest in increasing public attitudes toward and beliefs about mathematics and science, as much scientific work is publicly funded (discussed in Miller 2004).

Unfortunately, elementary teachers' inaccurate understanding of the NoS and their negative beliefs and attitudes may negatively impact their students' learning in several ways; they may spend less time on science, use non-ideal teaching methods, and transmit their negative attitudes to their students (Abell and Smith 1994; Harlen and Holroyd 1997; Irez 2006; Otero and Gray 2008; Palmer 2002; Ucar and Sanalan 2011). Children's foundational understandings of mathematical and scientific fields, as well as their interests and career ambitions, are formed in elementary school and shaped by their teachers' beliefs and attitudes (Bybee and Fuchs 2006; reviewed in DeJarnette 2012; Harlen and Holroyd 1997; Nadelson et al. 2013; Swift and Watkins 2004). More positively, studies have found that attempts to improve pre-service and in-service teachers' science beliefs and attitudes, as well as the use of methods such as hands-on and inquiry-based approaches, can be effective (Campbell et al. 2011; Herman et al. 2013; Riegle-Crumb et al. 2015), and can even improve their students' attitudes toward science (e.g., Akerson and Hanuscin 2007; Smith 2015).

To promote greater understanding of the NoS, teachers must conscientiously plan for and purposely teach NoS understanding as an important instructional objective just as they teach fundamental science ideas (Herman et al. 2013; Lederman 1999). Teachers should draw student attention to targeted NoS ideas so that students reflect on those ideas (e.g., Abd-El-Khalick and Lederman 2000; Akindehin 1988). Finally, students' NoS understanding must be assessed (Clough 2011a) so that teachers can make informed pedagogical decisions (Herman et al. 2013). To improve NoS teacher education efforts, we must understand teachers' NoS implementation practices and the extent to which teacher education programs prepare teachers who *do* accurately and effectively teach the NoS. McGinnis et al. (2002) pointed out that although it is not common for investigations to focus simultaneously on attitudes and beliefs about mathematics and science and the teaching of those subjects, there is an urgent need for this type of study as global attempts occur to enact standard-based recommendations that require making connections among the sciences and mathematics in both teacher preparation programs and in K-20 education (NGSS Lead States 2013; National Research Council 1996; Rutherford and Ahlgren 1989). The current study contributes directly to this knowledge base and may provide important information regarding efforts to prepare science teachers who will demonstrate positive and accurate attitudes and beliefs about mathematics and science and the effective teaching of these topics. Pre-service teachers in this study completed a physics course for pre-service teachers with a curriculum specifically designed to enhance understanding of the NoS, while students in courses designed for Science, Technology, Engineering, and Mathematics (STEM) and non-STEM majors received a standard inquiry-based curriculum.

Impact of Interventions to Improve Pre-Service Teachers' Beliefs and Attitudes

Classroom interventions have been shown to improve understanding of the NoS, and beliefs and attitudes about the NoS and about mathematics and science in pre-service elementary teaching candidates (Akerson et al. 2000; Akerson and Hanuscin 2007; Brewe et al. 2009; Elby 2001; Lindsey et al. 2012; Otero and Gray 2008). In one study, NoS teaching practices and the factors that affected these practices in 14 secondary pre-service teachers in a master of arts in teaching (MAT) program clearly emphasizing the NoS and its role in reform-based practices were examined (Abd-El-Khalick et al. 1998). During their student teaching, 12 of the 14 participants reported that they believed they had taught the NoS. However, discrepancies between their reports and classroom observations and supervisor notes showed that the NoS was addressed much less frequently than reported by student teachers. Abd-El-Khalick et al. (1998) concluded that either the pre-service teachers did not actually emphasize the NoS, or they believed that their students could learn it implicitly. The latter interpretation is particularly problematic because teachers are assuming that their students will implicitly learn the NoS, despite evidence that it is not being taught. In a follow-up study, Bell et al. (2000) examined whether changing the course instructional sequence in the program studied by Abd-El-Khalick et al. (1998) would positively influence pre-service teachers' NoS teaching practices. Results were more positive, indicating that nine of the 11 pre-service teachers explicitly implemented NoS instruction during their student teaching. However, as in the first study, pre-service teachers did not include the NoS in formal instructional objectives, and of the 11 teachers, only one reported formally assessing students' conceptions of the NoS. In a later in-depth qualitative study, Schwartz and Lederman (2002) examined factors that affected implementation of NoS teaching in two first-year teachers who had completed a program similar to Bell et al.'s (2000). Although both teachers demonstrated knowledge of both the NoS and NoS pedagogical content knowledge (PCK), they also had difficulty teaching the NoS within the context of science content and inquiry over the academic year, reporting that teaching required science content took precedence within institutional constraints.

In a larger study, McGinnis et al. (2002) used the Attitudes and Beliefs about the Nature of and the Teaching of Mathematics and Science survey, also employed in the present study, to compare attitudes and beliefs of 486 undergraduate students enrolled in courses incorporating standards-based instruction and a curriculum specifically designed to foster improvements in attitudes about the nature of mathematics and science and the teaching of mathematics and science. The courses contained two types of students: those enrolled in the intervention program, which prepared specialist mathematics and science elementary and middle-level teachers, and those in a standard teacher preparation program. The intervention teacher candidates began their courses with more positive subscale scores (all were above 3.48 on a 5 point scale, with higher scores indicating more positive beliefs) for beliefs about mathematics and science, attitudes toward mathematics and science, attitudes toward learning to teach mathematics and science, and attitudes toward teaching mathematics and science than those enrolled in the standard program type (all scores were above 3.06), and most effect sizes were moderate. For most subscales, the gap widened between these two groups by the end of the course, in part, because subscale scores for beliefs about mathematics and science and attitudes toward learning to teach mathematics and science declined over the course of the semester for teachers in the standard preparation program (McGinnis et al. 2002). In the same study, 446 of the teacher candidates who received the intervention program completed the same survey seven times over a period of 2.5 years, providing a series of seven snapshots that described the typical attitudes and beliefs of students at seven consecutive times. Results showed that all subscale scores rose significantly with moderate effect sizes, aside from one subscore scale, which had reached a ceiling effect in both early and later administrations of the survey. The researchers concluded that the study results provided support for the positive impact of reform-based teaching in subject matter courses and in pedagogy courses for pre-service science and mathematics teachers (McGinnis et al. 2002).

In a more recent study, Herman et al. (2013) conducted a qualitative study examining 13 teachers' NoS understanding and instructional practices 2–5 years after completing an intensive secondary science education program that included a NoS-specific course combined with NoS instruction throughout all other science education coursework. Post-intervention, six of the 13 teachers' understanding of the NoS were classified as informed, six were classified as transitional, and the remaining teacher's views of NoS were unclassifiable as a result of inadequate data. Results were slightly different in practice: classroom observations and artifacts showed that four of the 13 teachers were rated as high, five were rated as medium, and the four remaining participants were rated as low overall NoS implementers (Herman et al. 2013). Akerson et al. (2006) reinforce the importance of providing more than a single course to develop pre-service teachers' understanding of the NoS. In a study of 19 pre-service teachers assessed pre- and post-instruction, Lederman et al. (2002), found pre-service teachers' views of the NoS improved across the semester, but they later reverted to an inadequate understanding of the NoS when interviewed 5 months later.

Discipline-Based Nature of Science Research

Recently, there has been an increase in the study of the NoS and the development of scientist-like thinking within discipline-based education research in physics. Much of this research has been performed in the United States (US) and utilized the common practice in US institutions of offering physics classes with differing mathematics requirements to examine students with different career intentions. Most US institutions offer two introductory course sequences: College Physics, which requires algebra and trigonometry, and University Physics, which requires calculus. Student enrollment depends on which STEM major they have declared. As a result, physical scientists, mathematicians, and engineers make up the vast majority of students in University Physics, and life sciences majors (as well as majors from STEM disciplines with less rigorous mathematics requirements) make up the majority of students in College Physics. Many universities also offer a Conceptual Physics course requiring minimal use of mathematics. Conceptual Physics fulfills general science elective requirements, but does not fulfill the requirements of STEM degrees and, therefore, non-STEM majors make up the majority of students in this course.

Both STEM and non-STEM majors view physics as a series of disconnected facts handed down from authorities such as professors with little connection to the real world (Gray et al. 2008). Results from studies employing different instruments show that students have difficulty learning how scientific knowledge is constructed and that their levels of sophistication as measured by these instruments decline over a semester-long science course, even though their content knowledge may increase (Otero and Gray 2008; Pollock 2006; Redish et al. 1998). Several studies have shown that pre-service elementary teachers,' STEM, and non-STEM students' beliefs about scientist-like thinking decline in introductory physics courses, despite observed increases in physics conceptual inventory scores (Adams et al. 2006; Pollock 2006; Redish et al. 1998).

Much of the research within physics has employed the Colorado Learning Attitudes about Science Survey (CLASS) which was developed to probe the physicist-like thinking of students (Adams et al. 2006). The CLASS assesses shifts in several categories: overall, personal interest in physics, sense-making effort, real world applications of physics, and the relation of conceptual and quantitative reasoning. Positive changes over the course of the semester indicate an increase in the rate that students report the same attitude as physics faculty toward the statements in the survey. The CLASS, then, probes specific reasoning patterns identified by expert practitioners in a scientific field as important to practice in that field. These include the role of conceptual understanding in physics problem solving, the need for reasoning as opposed to memorization, and the need to attach meaning to mathematical expressions. The CLASS includes a personal interest subscale, but this measures the degree to which the student finds physics useful or relevant to his or her life or the degree to which they enjoy the tasks assigned in a physics class. Although the CLASS does not assess attitudes toward science, beliefs about the nature of science, or attitudes toward the teaching of science specifically as investigated in this study, one would hypothesize a greater personal interest in physics would be related to more positive attitudes toward science, and more expert-like thinking would be associated with more accurate beliefs about the nature of science. As such, CLASS results provide related, but parallel, evidence when compared with the results of this study.

In a study similar to the current one, Otero and Gray (2008) administered pre- and post-CLASS surveys to 182 pre-service teachers at nine institutions enrolled in reformed physics and physical science courses incorporating inquiry-based curricula designed by Goldberg et al. (2006) for pre-service elementary teachers, the Physics for Elementary Teachers (PET) curriculum, and compared their responses with those from 50 pre-service teachers in an alternate physical science course for teachers and 715 non-teachers in other physics classes. The PET curriculum was specifically designed to develop elementary teachers' understanding of the processes of science (Goldberg et al. 2006) and is unique in that it addresses the NoS (Otero and Gray 2008) and pedagogy (Goldberg et al. 2006) integrated with physics content. Results showed an average shift upward of 8.8% in the reformed PET courses compared to average, more negative shifts of − 6.1 to + 2.9% found in the other physical science courses for teachers. In the reformed PET courses, shifts were highest in personal interest, problem-solving sophistication, conceptual understanding, and applied conceptual understanding. They also report a positive shift of + 1.0 in Conceptual Physics (n = 76), a negative shift of − 9.8 in College Physics (n = 35), and a range of shifts of − 8.2 to + 1.5 in three

University Physics classes ($n = 604$). The researchers state that it was possible that the conceptual nature of the PET course could have led to the atypical positive shifts on the CLASS by itself, but they believe that explicit instruction regarding the NoS and the nature of learning accounted at least in part for students' gains. Regardless of the causal variable or combination of variables, reformed curricula effectively created positive shifts among pre-service teachers in CLASS responses (Otero and Gray 2008).

Many other researchers agree that attempts to improve teachers' conceptions of the NoS are most effective when they are explicit and encourage reflection (Abd-El-Khalick and Lederman 2000; Akerson et al. 2011; Elby 2001; McGinnis et al. 1997; McGinnis et al. 1998; McGinnis and Parker 1999; McGinnis et al. 2002; see Lindsey et al. 2012 for an exception to explicit instruction), as well as when they directly address epistemology and the nature of science and learning (Otero and Gray 2008). Other factors that influence the development of NoS beliefs include using a deep-processing learning approach, internalizing the utility of teaching and learning about the NoS, and understanding science and religion as separate, not competing, ways of knowing (Abd-El-Khalick and Akerson 2004).

Most studies using the CLASS instrument find a decrease in physics students' scientist-like beliefs across introductory physics courses (e.g., Adams et al. 2006; Kost-Smith et al. 2010). In contrast to results from other studies, Brewe et al. (2009) studied the progression of attitudinal shifts over two sequential semesters using the CLASS and found a significant increase in positive attitudes in two Modeling Instruction courses. Modeling Instruction (American Modeling Teacher's Association 2017) is a popular reformed physics curriculum that helps students learn physics in the context of building real-world models of physical systems. This curriculum is not directed toward pre-service teachers, and this observation shows that reformed instruction can improve scientist-like thinking for all physics students.

In the current study, changes in beliefs about and attitudes toward science and mathematics, as well as the teaching of science and mathematics, were measured over the course of each semester between fall 2003 and spring 2014 in pre-service elementary teachers and in students concurrently taking one of three other physics courses: Conceptual Physics, College Physics, and University Physics. The current study also investigated the effects of the PET curriculum designed to improve pre-service elementary school teachers' attitudes and beliefs about science and mathematics. The current study adds to the understanding of pre-service teacher's attitudes toward mathematics and science, beliefs about the NoS, and beliefs about the teaching of mathematics and science by comparing pre-service teachers to other STEM and non-STEM physics students. It extends previous work using the CLASS by employing an instrument that more broadly probes the constructs of beliefs about and attitudes toward science and mathematics as well as attitudes toward teaching these subjects. The interrelation of these constructs for different student populations as well as changes in the relationships between these constructs across time was also explored.

Research Questions

(1) Are pre-service teachers' beliefs about the nature of mathematics and science, attitudes toward mathematics and science, and beliefs about the teaching of mathematics and science different from those of STEM and non-STEM major students enrolled in other physics courses? How do these attitudes and beliefs change during their physics course compared to STEM and non-STEM major students in other physics courses?

(2) Does the relationship between the subscales of science and mathematics attitudes and beliefs differ for pre-service teachers, non-STEM major students, and STEM major students?

Methods

Context for Research The study was performed at a large public land-grant university enrolling 25,000 students in the Southern United States. The structure of introductory physics courses at this institution was very similar to that of most US universities as summarized in the introduction. Four physics course sequences were offered: University Physics, College Physics, Conceptual Physics, and Physics for Elementary Teachers (PET). University Physics, College Physics, and Conceptual Physics were presented in large lecture sections ($N > 100$) with a required integrated laboratory component while PET was taught entirely in the laboratory setting with classes of approximately 30 students. The Conceptual, College, and University Physics courses had undergone a revision to inquiry-based laboratories prior to the period studied and were not subsequently revised. The same instructor taught all sections of PET for the duration of study. This instructor also shared instructional responsibilities with several other instructors in Conceptual Physics and did not teach either the College or University Physics classes. Several different instructors taught College Physics and University Physics; however, there was no overlap between the College Physics instructors and the University Physics instructors. As such, the instructors of the four courses were for the most part independent and did not overlap between the courses.

1. *University Physics* was a two-semester, calculus-based course sequence required for quantitative physical science

majors such as physics, mathematics, chemistry, and engineering whose degrees require mathematics beyond Calculus 1.

2. *College Physics* was a two-semester, algebra and trigonometry-based course sequence taken by science students whose majors did not require mathematics beyond Calculus 1. The majority of students in the course were life sciences majors, but many other majors were represented such as geology and anthropology.
3. *Conceptual Physics* was a single-semester course with minimal mathematics prerequisites used to satisfy general science requirements. Conceptual Physics students were non-STEM majors. The conceptual physics class at the institution studied presented conceptual physics in the context of societal issues with the goal of producing better informed citizens and motivated students.

   In the current study, College and University Physics students are referred to as STEM majors and Conceptual Physics students as non-STEM majors.
4. *Physics for Elementary Teachers*. The university also offered a fourth introductory physics class specifically designed for pre-service elementary teachers to develop their understanding of the processes of science (Goldberg et al. 2006, 2007). The university and the broader physics education community acknowledge the central role elementary teachers have in shaping future STEM students and influencing the K-12 course decisions that make a STEM career possible. The overarching theme of PET follows Clough and Olson's (2004) recommendations that NoS should be accurately and consistently addressed in the context of science content instruction and focuses on the themes of interactions, energy, forces, and fields, as opposed to being incorporated periodically and inconsistently in a science course. This curriculum has been successful in a variety of contexts, including secondary school physics classrooms (Ross and Otero 2013) and workshops for active teachers (Harlow 2007) and has demonstrated that positive changes occur in its students thinking like scientists (Otero and Gray 2008).

In the PET course, students completed six modules to explore important topics in physics using the scientific method. The majority of class time was spent with students performing open exploration of phenomena (such as the domain model of magnetism) with simple, elementary classroom-appropriate equipment (i.e., bar magnets and iron nails). Students formed hypotheses, developed models of physical phenomena, designed experiments to test their hypotheses, and carried out and interpreted the results of those experiments. The class was developed to model the real application of the scientific method and to provide a model of inquiry-driven instruction that has been shown to engage students and promote long-term learning (e.g., Keys and Bryan 2001; Olson and Loucks-Horsley 2000). The course was required for the elementary education major, and the overwhelming majority of students in this class planned to become elementary teachers.

Measures McGinnis et al.'s (1997) *Attitudes and Beliefs about the Nature of and the Teaching of Mathematics and Science* survey was used to measure attitudes toward and beliefs about science and mathematics. This instrument was originally developed to assess the effectiveness of a teacher preparation program and consists of 41 items that encompass five subscales. The instrument was explicitly constructed to be applied to both future teachers and students in introductory STEM courses who did not intend to teach. Both teaching candidates and non-teaching candidates including STEM and non-STEM majors were included in each stage of the validation of the instrument. Two of the subscales featured items that were only asked of future teachers and were not included in this study. All items were answered using a five-point Likert-type scale ranging from 1 (*Strongly agree*) to 5 (*Strongly disagree*), with midpoints 2 (*Sort of agree*), 3 (*Not sure*), and 4 (*Sort of disagree*). The instrument employed inverted scaling with low scores being more positive and the reverse-coding of many of the instrument items. Scores in the current study were recoded so that higher scores represent more accurate beliefs and more positive attitudes. The reported reliability coefficients were calculated from the aggregated dataset collected for this study.

Subscale 1 (*F1*): *Beliefs about the nature of mathematics and science*. This subscale (pretest $\alpha = .78$; posttest $\alpha = .81$) reflects beliefs about the nature of mathematics and science (e.g., "Mathematics consists of unrelated topics (e.g., algebra, arithmetic, calculus, and geometry) [reverse-coded];" "Science is a constantly expanding field").

Subscale 2 (*F2*): *Attitudes toward mathematics and science*. This subscale (pretest $\alpha = .80$; posttest $\alpha = .80$) reflects attitudes about or toward mathematics and science (e.g., "I like science;" "I am looking forward to taking more mathematics courses").

Subscale 3 (*F3*): *Beliefs about the teaching of mathematics and science.* This subscale (pretest $\alpha = .63$; posttest $\alpha = .68$) reflects beliefs about the teaching of mathematics and science (e.g., "Students should be given regular opportunities to think about what they have learned in the mathematics classroom;" "Small group activity should be a regular part of the science classroom").

Sample Informed consent was obtained from all individual participants included in the study. A total of 5646 student responses were collected from the four physics courses during the study. McGinnis et al.'s (1997) *Attitudes and Beliefs about the*

Nature of and the Teaching of Mathematics and Science survey instrument was administered electronically once at the beginning and end of each physics course sequence; participation was optional and anonymous. Descriptive statistics and graphical analyses indicated that the study variables did not change substantially over the 10 years studied. The student population had not experienced the changes in K-12 education brought on by implementation of the Common Core or Next Generation Science Standards because they were enrolled prior to their implementation. About half (45.7%) of participants were male and most (93.4%) were white. The majority of the students in PET were women, while the majority of students in University Physics were men; in the other two courses, the number of women enrolled was slightly higher than the number of men (see Table 1 for demographic information by course).

Full class rosters were available for the University Physics courses. During the period studied, 5091 students enrolled in the first course in the sequence and 3291 in the second course in the sequence. The difference in enrollments occurred because the second course was not required for all majors. Of the 5091 students in the first course, 3190 completed the survey instrument (63%). Of the 3291 students in the second course, 2790 completed the survey instrument (85%). The difference in participation rates likely resulted from giving the survey very early in the semester in the first course while enrollments were still fluctuating. The 1450 student matched pre/post sample used in the analysis would represent 28% of the enrollment in the first course and 44% of the enrollment in the second course. Grade data was also available in the second course. For all students who completed the course in the period studied, the average course grade was $M = 3.09$, SD = 1.03 on the standard four-point scale with "*A*" = 4 and "*F*" = 0. For students in the matched sample, the course grade was slightly higher, $M = 3.28$, $SD = .86$. To be included in the sample, a student had to attend class on the day the survey was given; the difference in grades between the overall student population and the matched sample probably occurred because more successful students have higher attendance rates. While the difference is significant [$t(3171) = 6.35$, $p < .001$], the effect size is small (Cohen's $d = .20$). We conclude that the students in the matched sample were therefore slightly more academically successful than the average student in the course, but the difference was fairly small and should have a small effect on the conclusions drawn. Overall roster data was not available for the other courses, but the survey instruments were given under the similar conditions and participation rates should be similar.

Results

Research Question 1 Are pre-service teachers' beliefs about the nature of mathematics and science, attitudes toward mathematics and science, and beliefs about the teaching of mathematics and science different from those of STEM and non-STEM major students enrolled in other physics courses? How do these attitudes and beliefs change during their physics course compared to STEM and non-STEM major students in other physics courses? Research Question 1 was tested using a series of four repeated-measure ANOVAs. In addition to time across the course sequence (whether pretest or posttest), the effects of course were tested. Main effects of course indicated mean-level differences, while time-by-course interaction

Table 1 Demographic representation by course

	College Physics ($n = 686$)	University Physics ($n = 1450$)	Physics for Elementary Teachers (PET; $n = 343$)	Conceptual Physics ($n = 4561$)
Gender				
Male	385 (43.1%)	1012 (69.8%)	18 (4.5%)	2200 (42.5%)
Female	508 (56.9%)	438 (30.2%)	381 (95.5%)	2974 (57.5%)
Ethnicity				
African-American	40 (4.5%)	57 (3.9%)	11 (2.8%)	230 (4.4%)
Asian/Pacific Islander	54 (6.0%)	85 (5.9%)	4 (1.0%)	135 (2.6%)
Caucasian	738 (82.6%)	1211 (83.5%)	368 (92.2%)	4458 (86.2%)
Hispanic	18 (2.0%)	44 (3.0%)	7 (1.8%)	169 (3.3%)
Other	43 (4.8%)	53 (3.7%)	9 (2.3%)	182 (3.5%)
No. of credits completed				
0–30	39 (4.4%)	945 (65.2%)	40 (10.0%)	960 (18.6%)
31–60	198 (22.2%)	335 (23.1%)	186 (46.6%)	2194 (42.4%)
61–90	394 (44.1%)	123 (8.5%)	147 (36.8%)	1308 (25.3%)
91+	242 (27.1%)	36 (2.5%)	25 (6.3%)	697 (13.5%)
Post-bac	20 (2.2%)	11 (0.8%)	1 (0.3%)	15 (0.3%)

Table 2 Descriptive statistics for subscales, pretest, and posttest, by course

	College Physics (n = 686)	University Physics (n = 1450)	Physics for Elementary Teachers (n = 343)	Conceptual Physics (n = 4561)
Beliefs about the nature of mathematics and science M (SD)				
Overall	3.48 (.53)	3.55 (.51)	3.48 (.58)	3.26 (.58)
Pretest	3.53 (.52)	3.63 (.52)	3.48 (.57)	3.32 (.60)
Posttest	3.43 (.60)	3.46 (.63)	3.49 (.66)	3.22 (.65)
Attitudes toward mathematics and science M (SD)				
Overall	3.73 (.61)	4.25 (.51)	3.12 (.81)	2.97 (.82)
Pretest	3.74 (.62)	4.36 (.52)	3.09 (.79)	2.96 (.85)
Posttest	3.73 (.66)	4.14 (.64)	3.14 (.92)	2.97 (.90)
Beliefs about the teaching of mathematics and science M (SD)				
Overall	3.86 (.48)	3.87 (.46)	4.09 (.44)	3.78 (.47)
Pretest	3.84 (.50)	3.83 (.51)	4.06 (.49)	3.78 (.51)
Posttest	3.88 (.53)	3.90 (.54)	4.13 (.47)	3.79 (.55)

effects indicated differences in slope. Means and standard deviations (overall, pretest, and posttest) are presented by course in Table 2. The results of the analysis of each subscale are in Table 3.

For the *beliefs about the nature of mathematics and science* subscale (Subscale 1) (see Table 3), an overall repeated measures ANOVA showed a significant difference across time, and that accurate beliefs decreased from the beginning (M = 3.43, SD = .58) to the end of the course sequences (M = 3.32, SD = .65). Values of .01, .06, and .14 correspond to small, medium, and large effect sizes for partial eta squared according to Cohen's benchmarks, although he recommended that effect sizes be evaluated relative to findings from similar studies (Cohen 1969; Lakens 2013; Richardson 2011). There was also a significant main effect of course. Posthoc analyses with a Bonferroni correction revealed that Conceptual Physics students had significantly more inaccurate beliefs than students in University Physics, College Physics, and PET. Finally, there was a significant time-by-course interaction (see Table 3). This interaction effect revealed that beliefs of students in PET did not change, while the beliefs of students in other courses decreased in accuracy over the course of each sequence.

For the *attitudes toward mathematics and science* subscale (Subscale 2) (see Table 3), an overall repeated measures ANOVA showed a significant difference across the course sequence. Positive attitudes decreased from the beginning (M = 3.38, SD = .98) to the end of the course sequences (M = 3.34, SD = .96). There was a significant main effect of course (see Table 3). Posthoc analyses with a Bonferroni correction revealed that all courses/student populations significantly differed from one another (all ps < .001). University Physics students had the most positive attitudes, followed by College Physics, PET, and Conceptual Physics students, respectively.

Finally, there was a significant interaction between time and course, which revealed that the attitudes of University Physics students decreased significantly, pre-service teachers decreased slightly but not significantly, and College Physics and Conceptual Physics students did not change significantly.

For the *beliefs about the teaching of mathematics and science* subscale (Subscale 3, see Table 3), an overall repeated measures ANOVA showed a significant difference across the course sequence. Beliefs were more positive at the end

Table 3 Main and interaction effects for subscales 1–3

Subscale	Effect	Wilks' Λ	df	F	p	η_p^2
1	Time	.992	1, 5642	44.46	< .001	.008
1	Course	–	3, 5642	98.25	< .001	.050
1	Time × course	.995	3, 5642	10.36	< .001	.005
2	Time	.998	1, 5642	9.45	.002	.002
2	Course	–	3, 5642	1194.95	< .001	.389
2	Time × course	.966	3, 5642	45.70	< .001	.024
3	Time	.998	1, 5642	12.81	< .001	.002
3	Course	–	3, 5642	48.59	< .001	.025
3	Time × course	.997	3, 5642	5.88	.001	.021

($M = 3.84$, $SD = .54$) of the course sequence than the beginning ($M = 3.81$, $SD = .51$). There was also a significant main effect of course. Posthoc analyses with a Bonferroni correction revealed that PET students had significantly more accurate beliefs than students in the other courses (all ps < .001), while Conceptual Physics students had significantly less accurate beliefs than STEM students in the other courses (all ps < .001). Finally, there was a significant interaction between time and course, which revealed that students in University Physics and PET reported increased accuracy of beliefs over the course sequence, while the beliefs of College Physics and Conceptual Physics students did not change.

Research Question 2 Does the relationship between the subscales of science and mathematics attitudes and beliefs differ for pre-service teachers, non-STEM major students, and STEM major students? To examine whether or not the relationships between the subscales of science and mathematics attitudes and beliefs differed for pre-service teachers, non-STEM major students, and STEM major students, averages were first computed by combining pretest/posttest responses for each subscale in each course and then Pearson's r correlations between subscales for each course were computed (see Table 4). Subscales F1 and F2 were significantly correlated for all courses except College Physics; however, this relationship was positive for the PET and University Physics courses and negative for the Conceptual Physics course. For subscales F1 and F3, there was a significant negative relationship for all courses except PET. Subscales F2 and F3 were significantly positively correlated in all courses.

Significant correlations were then compared using Fisher's r-to-z transformation to determine whether the correlations differed significantly for students in the four courses using the corrected Bonferroni significance level of 0.003 (see Table 5). Results indicated that the correlation for subscales F1 × F2 was larger in the PET courses than for the Conceptual Physics courses. The correlation for the F1 × F2 subscales was also larger for the University Physics courses than the Conceptual Physics courses.

Discussion

In the current study, aggregated responses from 10 years of assessments of attitudes toward mathematics and science, beliefs about the nature of mathematics and science, and beliefs about teaching mathematics and science were examined in pre-service teachers who received a curriculum specifically designed to increase scientist-like thinking; these results were compared with a parallel measurement of STEM and non-STEM students. Two research questions were addressed.

Research Question 1 Significant differences in *beliefs about the nature of mathematics and science* subscale (Subscale 1) were evident: Conceptual Physics (non-STEM) students had significantly more inaccurate beliefs than students in University Physics (STEM), College Physics (STEM), and Physics for Elementary Teachers (PET, see Tables 2 and 3). A significant interaction showed that although PET students initially held more inaccurate beliefs, their beliefs did not change over the course of the semester, but beliefs of students in other courses decreased in accuracy.

Scores for the *attitudes toward mathematics and science* subscale (Subscale 2) decreased significantly from the beginning to the end of the course sequence. All courses differed significantly from each other. University Physics students had the most positive attitudes, followed by College Physics students, PET students, and Conceptual Physics students, respectively. These findings are consistent with research showing that non-STEM college students have less scientist-like physics beliefs than STEM students (Gray et al. 2008) but extend these findings to show that the differences are not localized to physics-specific modes of scientific reasoning and extend to more general attitudes toward mathematics and science as a whole. A significant time by course interaction revealed that the attitudes of University Physics students decreased significantly, but PET, College Physics, and Conceptual Physics students did not change significantly.

PET students had significantly more accurate *beliefs about the teaching of mathematics and science* (Subscale 3) than students in the other courses, while Conceptual Physics students had significantly less accurate beliefs than STEM students. Further analyses revealed a significant interaction for this subscale: accuracy of beliefs increased over the course sequence for students in University Physics and PET while the beliefs of College Physics and Conceptual Physics students did not change.

Pre-service teachers' attitudes toward science and mathematics were much more like those of non-STEM students and were much lower than those of STEM students. While it is encouraging that pre-service teachers had the most accurate beliefs about the teaching of science and mathematics, this gap in the attitudes toward science and mathematics raises concerns that future students might be discouraged from pursuing STEM careers because of these attitudes. Negative implications of these differences in attitudes between STEM and non-STEM students, such as the importance of scientific literacy to an informed citizenry and support for scientific research, are discussed in depth elsewhere (e.g., Gauchat 2011; Turney 1996).

Research Question 2 To examine whether the relationship between the subscales of mathematics and science attitudes and beliefs differed for pre-service teachers, non-STEM major students, and STEM major students, averages were first

Table 4 Pearson's correlations between subscales for each course

Course	PET (n = 343)	ConP (n = 4561)	UnivP (n = 1450)	ColP (n = 686)
Subscales				
F1 × F2	.13*	−.13**	.10**	−.02
F1 × F3	−.05	−.15**	−.20**	−.13**
F2 × F3	.17**	.23**	.27**	.25**

PET Physics for Elementary Teachers, *ConP* Conceptual Physics, *UnivP* University Physics, *ColP* College Physics *p < .05; **p < .001. Pearson effect size conventions: .10 = small, .30 = medium, .50 = large

F1: Beliefs about the nature of mathematics and science

F2: Attitudes toward mathematics and science

F3: Beliefs about the teaching of mathematics and science

computed by combining pretest/posttest responses for each subscale in each course and then Pearson's r correlations between subscales for each course were computed (see Table 4). Comparisons between significant subscale correlations were then conducted to determine whether these subscale correlations differed significantly by course (see Table 5).

The *beliefs about the nature of mathematics and science* (Subscale 1) and *attitudes toward mathematics and science* (Subscale 2) subscale scores were significantly correlated for all courses except College Physics; however, this relationship was positive for PET and University Physics students and negative for the Conceptual Physics students. Conceptual Physics students were probably the most representative of the overall US college-educated population, and as such, it is worrisome that an increased understanding of the NoS was related to liking science and mathematics less. Comparison of the correlation coefficients revealed that correlations between the subscales *beliefs about the nature of mathematics and science* (Subscale 1) and *attitudes toward mathematics and science* (Subscale 2) were significantly larger in the PET courses than the Conceptual Physics courses. The correlation was also significantly higher for the University Physics courses than the Conceptual Physics courses. For students preparing to be teachers and for more mathematical STEM majors, more accurate beliefs about the nature of mathematics and science were reflected in more positive attitudes toward mathematics and science; however, for non-STEM students, an increased accuracy in their beliefs about the nature of mathematics and science was accompanied by less positive attitudes toward science and mathematics. For PET students whose attitudes toward mathematics and science more closely resemble non-STEM students, the positive correlation may represent a benefit of the PET curriculum. For non-STEM students, the negative correlation between these constructs suggests that efforts in non-STEM classes to improve knowledge of the NoS may have some unintended negative effects. It is possible that a course curriculum which increases both constructs for non-STEM students could be developed. The PET curriculum could serve as a starting point.

Table 5 Comparisons between subscale correlations for each course

		F1 × F2		F1 × F3		F2 × F3	
		z	p	z	p	z	p
PET	ConP	4.65	.001**	–		1.11	.13
	UnivP	–		–		1.75	.04
	ColP	–		–		1.26	.10
ConP	UnivP	7.66	.001**	1.71	.04	–	
UnivP	ColP	–		1.55	.06	–	

PET Physics for Elementary Teachers, *ConP* Conceptual Physics, *UnivP* University Physics, *ColP* College Physics **p < .001; Absolute values of z scores are reported.

The *beliefs about the nature of mathematics and science* (Subscale 1) and *beliefs about the teaching of mathematics and science* (Subscale 3) subscales were significantly negatively correlated for all courses *except* PET. While these results are encouraging for students enrolled in PET, they are a cause for concern among STEM and non-STEM majors, because one would hope that accurate NoS beliefs would be associated with more accurate beliefs about teaching science and mathematics. Students' beliefs about teaching should grow out of their experiences as learners which makes the negative correlations more worrisome; more pedagogically correct teaching should lead to more accurate beliefs about science and mathematics. This may suggest that the level of curricular reform required to produce more accurate beliefs about the NoS through a physics course sequence is substantial. The PET curriculum transforms the traditional learning experience and makes the development of an understanding of the scientific process a centerpiece of the instructional experience. Even with this focus, the PET curriculum still only achieves a constant level of NoS beliefs while the beliefs of students in the other classes decline.

The subscales *attitudes toward mathematics and science* (Subscale 2) and *beliefs about the teaching of mathematics and science* (Subscale 3) were significantly positively correlated in all courses. To the extent that students' beliefs about teaching science and mathematics resulted from their experiences in previous science and mathematics classes, more pedagogically correct instructional practice may lead to students with a greater enjoyment of science and mathematics.

Results from this study are similar to those found in previous studies, which show that teacher preparation courses with a curriculum specifically designed to explicitly (or in one case, implicitly: see Lindsey et al. 2012 for an exception) address and encourage reflection about the NoS are effective in improving (or slowing the deterioration of) attitudes and beliefs about the NoS at least in the short term, although the long-term effects are less evident (Abd-El-Khalick and Lederman 2000; Akerson et al. 2011; Elby 2001; Herman et al. 2013; McGinnis et al. 2002, Otero and Gray 2008). The pre-service teachers in the current study enrolled in courses specifically designed to enhance NoS beliefs exhibited several strengths. Pre-service teachers held very similar beliefs about the nature of mathematics and science to those of the STEM-major University and College Physics students. They had significantly more accurate beliefs about the teaching of mathematics and science than non-STEM Conceptual Physics students. Pre-service teachers also expressed more positive pedagogical beliefs and attitudes than students in other courses.

Pre-service teachers' scores on beliefs about teaching mathematics and science were higher than those of both STEM and non-STEM majors at the beginning of the course sequences. These beliefs, as well as those of University Physics students, increased from pretest to posttest while those in other groups remained the same. If a pre-service elementary teacher matriculated through the elementary teacher education program on the 8-semester sequence published by the university, the PET course would be taken in the fall semester of the sophomore year before any courses providing pedagogical training were taken. As such, differences between pre-service teachers and other students should not have been the result of previously completed education courses. Students do not always matriculate on the planned sequence, so some PET students may have brought pedagogical training from other courses into the physics course; however, they also benefited from the PET course in terms of science-specific teaching practices. The increase of PET students beliefs' about teaching mathematics and science are similar to those in previous studies (Abd-El-Khalick and Lederman 2000; Elby 2001; Herman et al. 2013; McGinnis et al. 2002; Otero and Gray 2008).

Pre-service teachers had less positive attitudes about mathematics and science than STEM majors; however, their attitudes were slightly more positive than non-STEM majors to whom they were quite similar. Pre-service elementary teachers' attitudes did not decrease over the course sequence unlike the attitudes of the STEM major University Physics students. The attitudes of both STEM and non-STEM major students decreased in previous research (e.g., Handal 2003; Mulholland and Wallace 1996; Palmer 2002; Shrigley 1974; Tosun 2000). Taking the pre-service teachers course did not further degrade pre-service teachers' attitudes toward mathematics and science; this suggests that the enhanced curriculum was effective in this regard, similar to other curricula that have improved pre-service teachers' science attitudes (e.g., Lindsey et al. 2012; Riegle-Crumb et al. 2015). However, the PET curriculum did not improve pre-service teachers' attitudes toward mathematics and science substantially. While the gap between STEM majors and pre-service teachers decreased over the course of a single semester, this resulted from a decrease in the attitudes of STEM majors over their physics course sequence.

McGinnis et al. (2002) found that pre-service teachers who received a curriculum to enhance attitudes and beliefs toward the nature of science and teaching of mathematics and science generally improved while those without the enhanced curriculum did not. In the current study, pre-service teachers' (along with University Physics students') *beliefs about the teaching of mathematics and science* improved slightly. Otero and Gray (2008) found substantial positive shifts on the CLASS (Adams et al. 2006) in reformed courses compared to a range of neutral to substantially negative shifts in other physics courses. This research extends research comparing the outcomes of the PET curriculum with that of other physics classes. This study did not find the increases in accurate beliefs about the NoS and positive attitudes toward science observed in previous studies (Otero and Gray 2008); however, PET students beliefs about the NoS did not change while students in other classes declined, and therefore, the impact of the PET curriculum was positive when compared with other physics classes. PET students were most like Conceptual Physics students in their attitudes toward science and would have enrolled in this class if the PET class had not been available. Converting the Likert scale to a Percentage of Maximum Possible scale shows that PET students had 4% more accurate beliefs about the NoS before instruction which grew to 7% more accurate beliefs post-instruction. The 7% advantage over non-PET courses is consistent with the effect reported by Otero and Gray (2008) for the CLASS. The PET curriculum also showed a positive effect on beliefs about the teaching of mathematics and science. This study also confirms, with substantially larger sample size, the observation that changes in attitudes and beliefs (as previously measured by the CLASS) differ by the level of physics course taken, with the strongest declines in the University Physics course taken by the most mathematical STEM majors. The CLASS is directly crafted to measure physicist-like thinking, and as such, it is quite possible that PET students would show greater changes on this instrument than on the more general instrument employed in this study.

The general decline in accuracy of NoS beliefs across physics courses suggests that physics courses are being taught in a way that fails to develop sophisticated beliefs about the nature and teaching of science and mathematics. Science courses designed for pre-service teachers have great potential to train students in NoS concepts, as they are often more focused on methods than on total mastery of the content (e.g., Kazempour 2014).

Limitations

In the present study, students self-selected into one of the four courses, which differed in both student populations (including demographic compositions, majors, and career intentions) and course structure (including prerequisites and course focuses). These naturally occurring and coinciding differences limit our ability to determine what variable or combination of variables is responsible for the differences found in mean-levels and trajectories of beliefs and attitudes. However, this study provides context missing in other studies that evaluate pre-service elementary teachers (e.g., reporting that these students have negative attitudes) without comparison to other naturally existing groups that is likely generalizable to other institutions. Another possible limitation is the scale employed. McGinnis et al. (1997) originally designed the survey to assess pre-service teacher's attitudes and beliefs, although it was tested on students who intended to teach and those who did not. The instrument was validated with a large sample (N = 486), but only four of the five subscales were found to be reliable. Had a different instrument been employed in the current study, results may have been different. The large sample in the present study is a strength; however, with such large sample sizes even relatively small differences are statistically significant (Gigerenzer 2004; Lin et al. 2013), and results of statistical analyses must be interpreted in terms of practical as well as statistical significance (Cohen 1990; Gelman and Stern 2006; Grice 2015). In the current study, most effect sizes were in the small range, with some effects in the moderate range, as was the case in McGinnis et al. (2002). In addition, this study utilized self-report data, which is subject to several types of response bias and may not accurately reflect actual behavior as was the case in Herman et al.'s study (Gonyea 2005; Herman et al. 2013; Herzog and Bowman 2011). Finally, this study was conducted at a single institution. Replication at other sites could help begin to disaggregate the effects of site-specific institutional setting from other variables.

In future studies, collecting and controlling for more demographic and academic background variables such as GPA and standardized test scores would allow for greater precision through controlling for known confounding variables. In addition, true experiments examining the effects of interventions to improve the understanding of the NoS could incorporate findings from the current study to improve pre-service teacher and non-STEM major attitudes about the NoS.

Conclusions and Future Study

The development of positive views of the nature of mathematics and science and the teaching of mathematics and science in pre-service teachers is necessary because elementary teachers are often the first representatives of the science community young children will have contact with and teachers' views will undoubtedly influence the views of their students (Otero and Gray 2008). In the current study, the enhanced curriculum that pre-service teachers received in a physics course for elementary teachers may have contributed to their generally more positive attitudes about the teaching of mathematics and science relative to STEM (College Physics) and non-STEM majors enrolled in other courses. Results of the current study suggest that pre-service elementary teachers and non-STEM major students have negative attitudes about mathematics and science relative to students pursuing STEM degrees. Future interventions could draw on pre-service teacher strengths to more successfully improve pre-service elementary teachers' and non-STEM majors' beliefs and attitudes about science, thus improving students' beliefs and attitudes.

Results from this study may provide researchers, policy makers, and elementary teachers with a greater understanding of pre-service elementary teachers regarding science and mathematics beliefs and attitudes. Rather than using a deficit model that compares pre-service teachers to scientific experts, the present study compared PET students to STEM and non-STEM major students, finding that the pre-service teachers had both strengths and weaknesses relative to other students. Negative attitudes continue to be a concern, but the pre-service teachers' more positive attitudes toward teaching and learning mathematics and science and increased accuracy of beliefs could provide compensation for or pathways to address this weakness.

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Compliance with Ethical Standards

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

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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