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Effect of Critical Thinking Education on Epistemically Unwarranted Beliefs in College Students

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Abstract The degree to which students hold *epistemically unwarranted beliefs*, beliefs not founded on reliable reasoning or credible data, can be used as a measure of critical thinking skills. To this end, college students (n = 806) were surveyed at the beginning and end of a semester. Epistemically unwarranted beliefs were pervasive. Several sections of a critical thinking class that specifically and directly addressed pseudoscience, taught by three different instructors, produced a large and significant reduction of those beliefs, but research methods classes and unrelated general education classes did not. Most likely to be reduced were beliefs in health pseudoscience and extraordinary life forms. Conspiracy theories were least likely to change. Demographic variables (gender, race, SES) were associated with beliefs at pre-test, but not related to reduction of belief as a result of the class. Similarly, academic indicators that suggest intelligence were related to belief at pre-test, but not change. The one exception was that reduction of belief in health pseudoscience was widespread in all groups at pre-test, but showed the greatest reduction among students with indicators of academic aptitude and achievement. We conclude that the educational approach of directly addressing pseudoscience is effective for changing beliefs, not just increasing knowledge, and that it works for most college students, not just a select subset.

Keywords Critical thinking · Pseudoscience · General education · Epistemically unwarranted beliefs · Evaluation · Educational outcomes

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Introduction

Belief in pseudoscience and the paranormal is alarmingly common in the United States. For instance, Gallup polls indicate that at least half of the US population believe in psychic healing and extra-sensory perception (ESP), and a third believe in haunted houses, possession by the devil, ghosts, telepathy, and extra-terrestrials visiting Earth (Newport and Strausberg 2001). More than a third (37%) of people surveyed in the United States believe in haunted houses, 25% believe in astrology, and 24% believe that extra-terrestrial beings have visited Earth (Lyons 2005). Even more recently, a nationally representative sample surveyed by Bader et al. (2011) revealed that 70–80% of the US population believes in at least one type of paranormal activity. Furthermore, belief in pseudoscience and the paranormal are associated with belief in conspiracy theories (Lobato et al. 2014) and with science denial (Lewandowsky et al. 2013). All of these beliefs are collectively referred to as Epistemically Unwarranted Beliefs (EUBs; Lobato et al. 2014), beliefs that are held despite a lack of empirical evidence to support them, or even in the face of empirical evidence to reject them.

Some of these EUBs may not be especially harmful, but others are potentially devastating. For instance, believing that ancient astronauts may have helped humans build the pyramids is bizarre but probably harmless. On the other hand, the anti-vaccination movement inspires otherwise conscientious parents to imperil their children's health and safety by rejecting safe and effective vaccines. This and other health-related EUBs cost untold dollars as well as pain and suffering.

Health-related EUBs represent an especially significant risk to health and substantial personal and societal financial costs as people waste time and money on pseudoscientific solutions to real problems and avoid solutions with empirically demonstrated effects. The measles outbreak of 2015, considered to be a product of the pseudoscientific anti-vaccination movement (Majumder et al. 2015), is one example of such. Another is the $34 billion dollars spent every year by the US public on alternative medicine (Nahin et al. 2009).

In addition to the very real consequences of health-related EUBs, conspiracy theories and science denial represent a very real risk to our political and societal well-being. Education is compromised by school boards that are afraid of teaching evolution and climate science. Political engagement is thwarted when citizens do not trust that their government is working toward their protection. Therefore, this is an issue in which society has a stake, and which is being addressed by publically funded higher education.

It is tempting to posit that improved science education will reduce belief in the paranormal and pseudoscience. Sagan famously asserted that belief in pseudoscience is inversely proportional to understanding of science (Sagan and Druyan 1997). Some limited support for this position exists. For instance, data from the 2008 General Social Survey (National Science Board 2010) reveal that those with a college education are significantly more likely than those without a college education to know that astrology has no scientific merit (78% vs 60%). Decades ago, Tobacyk (1984) found that among college students, paranormal beliefs are negatively correlated with college grade point average. Recent research has also found a relationship between scholastic aptitude and belief in the paranormal such that the better-performing students report fewer paranormal beliefs (Dyer and Hall 2015). In addition, Goode (2002) found that science knowledge in college students was negatively correlated with paranormal beliefs that are endorsed by mainstream religion.

But there is also considerable evidence to suggest that these relationships exist because education acts as a proxy for something else (possibly intelligence), and that what people

actually learn from their studies does not help them differentiate science from nonsense. Gallup polls, which survey a much more diverse sample than just current college students, suggest that a college education makes belief in *some* paranormal and pseudoscience topics less likely (e.g., clairvoyance, channeling, devil possession, ET visitation, astrology, haunted houses and ghosts), but that some other beliefs (e.g., psychic healing, ESP, telepathy) are actually *more* prevalent among those with college educations (Newport and Strausberg 2001). One study has even found that the longer people stay in college the more likely they are to believe in some types of pseudoscience and paranormal claims, specifically witchcraft, spiritualism, and precognition, while years in college did not have any relationship to belief in superstitions and cryptozoological creatures (Dyer and Hall 2015).

Not only is a college education generally inadequate to for reducing or preventing belief in nonsense, but it has also been determined that understanding of science, specifically, is not related to epistemically unwarranted belief. Goode (2002), measured science knowledge in a college sample and did not find any consistent relationship in his sample between science knowledge and paranormal beliefs not related to religion. He argues that higher education only works against religiously-based paranormal beliefs. Other studies have replicated the finding of no relationship between knowledge of scientific facts and skepticism about pseudoscientific claims (Johnson 2003; McLaughlin and McGill 2017), suggesting that education about science or how knowledge is produced scientifically is no guarantee of protection against nonsense.

However, rationality has been demonstrated to help people identify illogical and unsupported arguments, particularly conspiracy theories (Orosz et al. 2016). Maybe educators can teach people to think more rationally. Institutions of higher learning generally require all students to take a critical thinking class as part of general education, in the hope that students can learn how to appraise claims about truth, and therefore be more savvy about identifying and thus avoiding epistemically unwarranted beliefs. Studies of the effect of critical thinking instruction at all ages (from elementary school thru adult education programs) have been reviewed, and the results indicate that such education is only effective when it provides explicit instruction in critical thinking (Abrami et al. 2008). That meta-analysis revealed that immersing students in the practice of critical thinking, without identifying those activities as such but hoping that the students will "pick it up" by example is simply not effective. Evidence continues to accumulate that explicit instruction is required for the development of critical thinking (Marin and Halpern 2011). However, the transference of those academically measured critical thinking skills to personal beliefs is a slightly different question. Are students able to apply critical thinking skills to claims they encounter in their lives, and use critical thinking to determine which claims are warranted by evidence?

Studies using a pre-test/post-test design generally report a reduction in belief among students after taking a critical thinking course that explicitly addresses pseudoscience (Wesp and Montgomery 1998; Franz and Green 2013). Additional studies have been published that report the same finding along with evidence that there was no reduction in belief in a comparison group of students who did not take such a course (Gray 1985; Dougherty 2004; Kane et al. 2010; McLean and Miller 2010; McLaughlin and McGill 2017; Morier and Keeports 1994).

Methodological problems in this body of research, including lack of comparison groups in earlier studies, have been identified by Kane et al. (2010). However, the body of research has increased in recent years now includes several studies with comparison groups in addition to the original studies without. Another criticism is that students may simply report what they know their teacher wants to hear, especially if the data are not collected

anonymously (Kane et al. 2010). But once again, we now have a body of research, some of which is anonymous, some confidential (i.e., not known to the student's instructor), and some identified, and the results seem to be the same no matter what. Therefore, a consensus is emerging that direct instruction about pseudoscience does reduce personal belief in EUBs.

One methodological problem, however, remains. Sample sizes have been quite small. Most studies include data from only two or three small classes with a total sample size of less than 100 participants. The small sample size means that the intervention is generally provided by a single professor, conflating the effectiveness of a particular instructor with the content or method of the course. The small sample size also makes it impossible to analyze which beliefs are more or less likely to change as a result of the intervention, or to explore what kinds of students are more or less likely to experience a change in belief. One previously published study (Kane et al. 2010) does have a large sample size (n = 578) but suffers from a low rate of completion (only 326 students, 56% of the sample, completed both the pre- and post-tests) and the problem of all of the intervention classes being taught by the same instructor.

Therefore, the current research seeks to contribute to this body of knowledge by including a large sample size with intervention classes taught by multiple instructors from various disciplines. We used a simple pre- and post-test design, with a comparison group, to answer the following questions.

1. Does a critical thinking class that directly addresses pseudoscience reduce epistemically unwarranted beliefs? (Previous research strongly suggests that it will.) Does a research methods class that does not directly address pseudoscience reduce epistemically unwarranted beliefs? (Previous research suggests that it will not.)
2. Are certain categories of epistemically unwarranted beliefs more changeable than others in the face of direct instruction?
3. Are there qualities of the students (e.g., demographics, ideologies, academic indicators) that render them more or less able to change epistemically unwarranted beliefs in the face of direct instruction?

Methods

Researchers employed a pre- and post-test design with a large sample consisting of two intervention groups and a comparison group.

Interventions

The primary intervention being assessed (the Pseudoscience Instruction group) consisted of six sections of a critical thinking class called "Natural Science 4: Science and Nonsense," which explicitly addresses common human errors of perception and logic by applying critical thinking skills to the claims of specific epistemically unwarranted beliefs. This investigation included all sections of the course offered during a given semester at the institution. Three different instructors, one with a home discipline of physics, one chemistry, and one geology, taught this course. One section consisted of a cohort of freshman science majors. Another section consisted of a cohort of sophomores in the university's prestigious honors program. The course may be offered by any department in the College of Science

and Mathematics, and is specially designed to meet the requirement of a critical thinking GE class.

The main learning outcome of the course is for students to be able to distinguish scientific claims and reasoning from those of pseudoscience. The other student learning outcomes of these sections are typical of college critical thinking courses: Students will be able to (1) recognize, analyze, and evaluate arguments as they occur in real life, (2) detect the most common logical fallacies and the use of inappropriate rhetorical tactics, (3) identify perceptual, cognitive, and social biases in evaluation of evidence, (4) distinguish appropriate from inappropriate use of statistical and casual reasoning, (5) distinguish deductive from inferential logic and the appropriate scope of the conclusions from each, and (6) judge the reliability of experts, authorities, and the media.

Conceptually, the course is one that directly confronts pseudoscience, explaining the perceptual and cognitive biases that are used to support pseudoscience, contrasting the arguments of pseudoscience with those of science, and examining specific cases of science and pseudoscience to exercise the skills listed in all six critical thinking learning outcomes. Each instructor selects the specific examples of pseudoscience and science that he or she will use to illustrate these principles and practices. The three instructors of the course that were included in this study use different textbooks, and present the course from their own area of expertise. What they have in common is a pedagogical strategy of pointing out the critical thinking flaws of specific examples of pseudoscience.

Pedagogical methods that are shared across the instructors of this course include collaborative learning and interactive writing assignments. The primary collaborative assignment is a series of student group presentations, wherein students have some choice about a topic of pseudoscience, and one is explored each week. Students present the best evidence and arguments of both the proponents and critics based on the group's review of available literature and mandatory consultation with the instructor. The other students in the class then complete a writing assignment on that topic that is graded on a rubric that rewards the following skills: cogent evaluation of reasoning, the use of best information literacy practices in finding further resources, and appropriate consideration of the quality, relevancy, and sufficiency of evidence offered. The writing assignment instructions are the same each week and are designed to exercise skills including: identification of common fallacies of logic employed, identification of possible cognitive and perceptual biases, and finding trustworthy sources of information. With each week and each new EUB topic, these same goals are applied to increasingly complex subject matter, and students are provided with timely written feedback before the next iteration.

The topics of the student presentations are selected by the students from a list supplied by the instructor and are presented in an order of increasing complexity and potential for challenging core political or spiritual beliefs. The initial topics of the semester include ancient astronauts and bigfoot, where students do not typically have a personal stake in these topics and they can become comfortable and confident in offering critiques of the logic and claims. The topics become more complex and controversial through the semester at a level that matches the emerging expertise of the students, saving for the end topics such as homeopathy and climate change denialism, where evaluation of claims involves deeper knowledge, more intricate analysis, and strong personal beliefs are often challenged. The final project is a term paper, graded on similar criteria to those described above, where each student selects a topic not covered in class on which to apply their developing critical thinking skill set.

The second intervention group, (the Research Methods group) consisted of two research methods classes, one in Child and Family Science (Developmental Inquiry for

Practitioners) and one in Psychology (Experimental Research Methods). Two different instructors taught the two sections of the Child and Family Science methods class. Two different instructors taught the five sections of the Psychology methods class. Both courses address research design, data collection, and analysis of results. Neither explicitly teach students to beware of pseudoscience, but instead focus on the methods of scientific inquiry.

The Comparison group consisted of four lower-division GE courses that did not fulfill the university's critical thinking requirement and did not explicitly teach about pseudoscience or about the methods of science. One was a lifespan development class, one was an introduction to family science, one was about nutrition and health, and the fourth was an introduction to earth science. Four different instructors taught these four courses.

Sample

Students at a state university in a medium-sized California city during the fall semester of 2015 comprise the target population. The selected courses enrolled a total of 806 students, of whom 203 were in the pseudoscience instruction classes, 225 were in the research methods classes, and 378 were in the comparison classes. Due to the voluntary nature of participation, as well as the adding and dropping that happens in the early weeks of a college course and the random nature of individual absences, we finished the semester with full data (both pre- and post-test) from 590 students, which is 73% of the students originally enrolled in the selected courses.

The sample included more women than men, was racially diverse (primarily Latino, White, and Asian, with most Asians in the sample being Hmong), and split roughly into one-third Protestant Christian, one-third Catholic Christian, and one-quarter non-religious. However, the three groups were very different from each other on these and other demographic characteristics, as demonstrated in Table 1. ANOVA reveal that differences regarding gender, race/ethnicity, and academic major were statistically significantly. These group differences were noted in order to include them in subsequent multivariate analyses.

In the Pseudoscience Instruction group, at Time 1, 199 students completed the survey, out of the 203 students enrolled in the classes. A total of 147 completed the survey at Time 2. Altogether, 144 students in the Pseudoscience Instruction group completed both the Time 1 and Time 2 surveys. This is a 72% rate of full compliance.

In the Research Methods group, at Time 1, 205 students completed the survey, out of the 225 students enrolled in the classes. A total of 184 completed the survey at Time 2. Altogether, 165 students in the Research Methods group completed both the Time 1 and Time 2 surveys. This is a 73% rate of full compliance.

In the Comparison Group, at Time 1, 345 students completed the survey, out of the 378 students enrolled in the classes. A total of 262 completed the survey at Time 2. Altogether, 196 students in the comparison group completed both the Time 1 and Time 2 surveys. This is a 57% rate of full compliance.

Procedures

The research protocol was approved in advance by the Committee on the Protection of Human Subjects at the university where the research was conducted.

Students in selected courses completed surveys once during the first week of instruction at the beginning of the semester, and once within the final 2 weeks at the end of the semester. At both times, one of the researchers attended each class and

Table 1 Demographic characteristics

	Pseudoscience instruction (n = 208)	Research methods (n = 238)	Comparison (n = 413)
Full compliance	144 (72%)	165 (73%)	196 (57%)
Female**	90 (55%)	154 (85%)	163 (71%)
Religion			
None	44 (26%)	44 (24%)	46 (20%)
Catholic	52 (31%	66 (36%)	82 (35%)
Protestant	58 (34%)	54 (29%)	59 (25%)
Shamanism	7 (4%)	8 (4%)	29 (12%)
Other	9 (5%)	12 (7%)	17 (7%)
Race/ethnicity			
White**	61 (30%)	60 (26%)	57 (15%)
Asian**	32 (16%)	26 (11%)	88 (23%)
Latino	102 (50%)	135 (58%)	216 (55%)
Black*	5 (3%)	12 (5%)	23 (6%)
Other	3 (2%)	0	5 (1%)
Politically			
Conservative	28 (17%)	21 (12%)	25 (11%)
Middle of road	44 (27%)	49 (27%)	52 (23%)
Liberal	32 (19%)	38 (21%)	44 (19%)
Don't know	61 (37%)	72 (40%)	107 (47%)
Academic indicators**			
Major—Natural Science	49 (24%)	2 (1%)	18 (4%)
Major—Social Science	22 (11%)	220 (93%)	94 (23%)
Major—Applied Science	70 (34%)	6 (3%)	177 (44%)
Major—Arts & Humanities	22 (11%)	4 (2%)	25 (6%)
Major—Other	45 (22%)	4 (2%)	90 (22%)
Overall GPA	3.1	2.9	2.9
Freshman/Sophomore**	150 (91%)	13 (7%)	150 (65%)
Junior/Senior**	15 (9%)	169 (93%)	79 (34%)

*p < .05; **p < .01

invited students to participate during classtime. Participation was voluntary. Instructors did not give class credit for completing the survey.

One of the researchers, rather than instructor of the class, administered the questionnaires, informing students that their surveys would remain confidential. Instructors never had access to any raw data for their classes. Students were protected by virtue of having all data managed by the member of the research team who did not serve as instructor to any of the participating students. That researcher attended all classes, physically collected all data, assigned ID numbers to all surveys, and removed the consent forms, thereby destroying any link between survey and student name.

Measures

Prior researchers have used measures of EUBs, including the Paranormal Beliefs Scale (Tobacyk 2004), which has been extensively validated. We elected to create a new measure, albeit one that adopted the same structure as Tobacyk's measure and included some of the same items, in order to broaden the list of beliefs assessed. Because we were evaluating a particular educational intervention, we wanted to include the general categories of EUBs that are addressed by that course, and not all of them were included in The Paranormal Beliefs Scale. For instance, we wanted to include conspiracy theories, science denial, pseudoscience, and specific contemporary issues that we deem critical (e.g., anti-vaccine movement). Therefore, we produced a wide-ranging list of claims that are empirically testable and have generated a substantial amount of scientific scholarship, but for which there is not supporting evidence.

Time 1 and Time 2 measurement included an Inventory of Epistemically Unwarranted Beliefs (IEUB), created by the authors, designed to reflect the topic areas included in the Pseudoscience Instruction classes. The inventory includes a list of 37 items, along with a brief description of what each term means. The descriptions clarify terms for students who may not have heard of the phenomena, and identify exactly what aspect of that phenomenon we refer to, in case there are ambiguities in possible interpretations. Examples include: "Anti-Vaccine Movement – Routine childhood vaccines cause developmental problems such as autism in children," "Chiropractic – Manipulation of the back can effectively cure most physical maladies by aligning the spinal column," and "UFOs (Unidentified Flying Objects) – Spacecraft piloted by beings not from Earth sometimes visit Earth."

The IEUB also included 12 statements that are considered scientific facts. These were included as distractors and were used to cross-check for response sets. Examples include: "Mars Rover – NASA is currently exploring the surface of Mars with remotely controlled automated motor vehicles." The EUBs and statements of scientific fact were listed in alphabetical order, a strategy intended to obscure any themes and thereby reduce the risk of response sets.

Respondents indicated their agreement (on a 5-point Likert scale where 1 = "totally sure it's false", 3 = "not sure" and 5 = "totally sure it's true") with all items, including the EUBs and the scientific facts. We sometimes dichotomized responses so that a score of 4 ("unsure, but think it's true") and 5 ("totally sure it's true") were coded as belief, and 1–3 were coded as lack of belief.

Principal components analysis (oblimin rotation) on all Time 1 data (n = 747) yielded eight components with eigenvalues greater than 1.0. Two of those components had only two items loaded on them, but such short subscales are not generally theoretically useful. Additionally, those items had also loaded strongly on other existing components, where they made more sense theoretically. Therefore, we concluded that it was best to include them on the other components. When we conducted a confirmatory principal components analysis forcing only six components (see Table 2), we noted that each of the items that had previously comprised the very short subscales now loaded strongly on one of the remaining six components. Therefore, the IEUB has six subscales. We calculated each subscale as the mean rating (from 1 to 5) of the items included, with higher numbers indicating greater belief.

We calculated change scores in several ways. First, we subtracted the post-test score for any given subscale (and for the combined score of all epistemically unwarranted

Table 2 Principal components loadings for items on the IEUB

Item topic	Paranormal	Religion	Health	Extraordinary Life Forms	Conspiracy Theories	Ghosts
Lucky Numbers	.695	–	–	–	–	–
Therapeutic Touch	.653	–	–	–	–	–
Crystal Healing	.638	–	–	–	–	–
Extra Sensory Perception	.613	–	–	–	–	–
Psychokinesis	.603	–	–	–	–	–
Full Moon behavior	.593	–	–	–	–	–
Astrology	.572	–	–	–	–	–
Reincarnation	.564	–	–	–	–	–
Psychic Detectives	.508	–	–	–	–	–
Graphology	.273	–	–	–	–	–
Healing Prayer	–	− .753	–	–	–	–
Faith Healing	–	− .701	–	–	–	–
Creationism	–	− .666	–	–	–	–
Near Death Experiences	–	− .359	–	–	–	–
Acupuncture	–	–	.664	–	–	–
Chiropractic	–	–	.547	–	–	–
Use 15% of Brain	–	–	.496	–	–	–
Mozart Effect	–	–	.403	–	–	–
Homeopathy	–	–	.359	–	–	–
GMO Danger	–	–	.318	–	–	–
Alien Abduction	–	–	–	.830	–	–
UFO	–	–	–	.741	–	–
Area 51	–	–	–	.707	–	–
Ancient Astronauts	–	–	–	.699	–	–
Bigfoot	–	–	–	.525	–	–
Bermuda Triangle	–	–	–	.438	–	–
Chupacabra	–	–	–	.348	–	–
Moon Landing Hoax	–	–	–	–	.671	–
Holocaust Denial	–	–	–	–	.537	–
Anti-Vaccination	–	–	–	–	.464	–
Chemtrails	–	–	–	–	.452	–
Sept 11 Conspiracy	–	–	–	–	.380	–
Haunted Houses	–	–	–	–	–	.602
Satanic Ritual Abuse	–	–	–	–	–	.576
Ghosts	–	–	–	–	–	.585
Ouija Board	–	–	–	–	–	.436
Animism	–	–	–	–	–	.342

beliefs) from the pre-test score, yielding a continuous change score that could potentially range from − 5 (gained total belief in every item on scale from total disbelief to begin with) to + 5 (lost belief in every item on scale from total belief to begin with). Obviously, since no student started fully believing or disbelieving everything, the potential change scores really fall within a much narrower range. We then dichotomized the

change scores to identify students who reduced belief and those who did not. In order to dichotomize, we defined reduction of belief as a change score of 0.72 or higher. The cutoff of 0.72 was used because the comparison group (with an average change score of 0.0, no change) had a standard deviation of 0.36. Two standard deviations includes 95% of the comparison sample, and therefore can be considered random fluctuation.

In addition, students completed the following measures only at Time 1:

a. Epistemic curiosity questionnaire (Mussel 2010)—this is a validated and widely used tool in research on curiosity that emphasizes an intellectual form of curiosity, a desire to find answers to questions and solutions to problems, and the persistence required to pursue those answers and solutions.
b. Religious Emphasis Scale (Altemeyer 1988)—this is a measure of the degree to which religion was emphasized in one's childhood upbringing. It includes items about attending religious services, prayer and religious study, religious holidays, religious morals, and youth groups.
c. Religiosity measure (Rohrbaugh and Jessor 1975)—this instrument assesses various forms of current religiosity, including religious affiliation, participation in religious rituals, personal religious devotions, use of religion to make personal decisions, and the degree of comfort derived from religious belief.
d. Lifelong learning (Dyer and Hall 2015)—this instrument asks very briefly about the frequency of travel and of looking up things up in dictionaries and encyclopedias. It is conceptualized as a measure of self-directed (rather than academic) predilection toward learning.
e. Demographic questionnaire—this instrument was created by the authors, and asks about ethnicity, social status, and political orientation.

Finally, we obtained information about the students' SAT score, high school GPA, academic major, year in school, and cumulative GPA in college through university records.

Results

Descriptive Statistics

At time 1 (the beginning of the semester), 99% of the sample (all but five students) reported believing at least one of the included epistemically unwarranted beliefs, endorsing an average of 12.4 of the 37 possible epistemically unwarranted beliefs (EUBs). Table 3 presents the number of beliefs endorsed by students in each group at the pre-test, along with average belief scores (on a scale of 1–5) for each category of beliefs. Students in all three groups were most likely to endorse EUBs associated with Health, and the least likely to endorse Conspiracy Theories. ANOVA indicate that the three groups are significantly different on beliefs at the pre-test, with the Comparison group reporting the highest levels of belief on all subscales, and students enrolled in the Pseudoscience classes reporting the lowest levels of belief.

The difference in belief scores at time 1 may, in part, reflect a selection effect, given that students must choose to take the Pseudoscience class from among several options to meet the Critical Thinking GE requirement. Students in the Pseudoscience Instruction group are not just less believing, they are also overwhelmingly freshmen and sophomores, more

Table 3 Epistemically unwarranted beliefs at time 1

	Pseudoscience instruction (n = 195)	Research methods (n = 201)	Comparison (n = 292)	Mean score ANOVA
	Mean number of items believed; mean score	Mean number of items believed; mean score	Mean number of items believed; mean score	F statistic p value
Paranormal*** out of 10 possible; on 5 point scale	2.0; 2.3	2.2; 2.4	2.9; 2.7	F = 17.76 p < .0001
Religion* out of 4 possible; on 5 point scale	1.5; 3.0	1.7; 3.1	1.9; 3.2	F = 3.85 p = .022
Health* out of 6 possible; on 5 point scale	2.9; 3.4	3.3; 3.6	3.2; 3.6	F = 4.59 p = .010
Extraordinary Life Forms*** out of 7 possible; on 5 point scale	2.0; 2.6	1.6; 2.4	2.1; 2.8	F = 11.69 p < .0001
Conspiracy Theories*** out of 5 possible; on 5 point scale	0.8; 2.1	0.8; 2.1	0.9; 2.3	F = 12.03 p < .0001
Ghosts*** out of 5 possible; on 5 point scale	2.1; 3.1	2.2; 3.2	2.6; 3.4	F = 9.48 p < .0001
Total*** out of 37 possible on 5 point scale	11.2; 2.7	11.7; 2.7	13.7; 3.0	F = 17.44 p < .0001

*p < .05; ***p < .0001

likely to be male, more likely to be Natural Science or Applied Science majors and very unlikely to be Social Science majors. It should be noted that the Pseudoscience Instruction classes are not in direct competition with either the Research Methods classes or the Comparison classes. A student could potentially be in all three groups simultaneously, or they could potentially take classes in all three groups during their time in college. Nevertheless, some self-selection process appears to be at play such that male, science majors, lower-division students who are already somewhat skeptical register for the Pseudoscience class. These differences are addressed in the analyses that follow.

Question 1: Can Classes Reduce Epistemically Unwarranted Beliefs?

While the answer to this question is fairly well-established in the literature, a replication of previous findings lends support to the validity of the measures used. We used repeated measures ANOVA to compare pre- and post-test scores so that each student served as his or her own control. This analysis eliminates the effects of selection bias with regard to group differences in pre-test belief scores. The changes in total EUBs from Time 1 to Time 2 for all three groups are demonstrated graphically in Fig. 1.

We did not expect to find a change in beliefs for students in the comparison group, and we did not. The analyses based on comparison group students for whom both sets of data are complete are detailed in Table 4. All subscale scores were unchanged from Time 1 to Time 2. We did expect to find a reduction in belief in the Pseudoscience Instruction group, and the data confirmed our expectation. The analyses based on those students for whom both sets of data are complete are also detailed in Table 4. We see statistically significant reduction in epistemically unwarranted beliefs in every subscale, with effect sizes larger than a standard deviation. We hoped for a similar reduction in belief in the Research Methods group, but the data reveal only small statistically significant changes in one belief subscale, Paranormal Beliefs, with a small effect size. The total EUB score is also statistically significantly changed, but also with a small effect size.

In order to more fully explore the potential impact of selection effects on the observed change of beliefs in the primary intervention group, we employed a forward stepwise linear regression analysis in addition to the repeated measures ANOVA. We used post-test IEUB score as the outcome variable. Predictor variables included pseudoscience group,

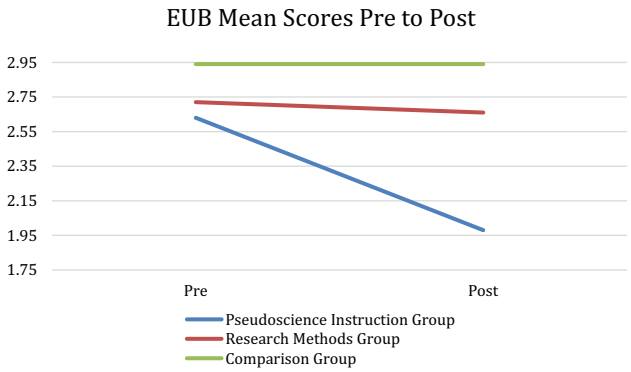

Fig. 1 Pre-test and post-test belief scores for all groups

Table 4 Repeated measures ANOVA

Belief	Time 1 Mean (SD)	Time 2 Mean (SD)	ANOVA F statistic; p value	Effect size Cohen's d
Comparison group				
Paranormal	2.7 (.82)	2.7 (.78)	F = 0.40; p = .53	
Religion	3.2 (1.03)	3.2 (.95)	F = 1.84; p = .28	
Health	3.6 (.66)	3.6 (.66)	F = 0.56; p = .45	
Extraordinary Life Forms	2.8 (.90)	2.8 (.93)	F = 0.04; p = .84	
Conspiracy Theories	2.29 (.61)	2.27 (.65)	F = 0.09; p = .76	
Ghosts	3.4 (.99)	3.3 (.9)	F = 1.38; p = .24	
Total	3.0 (.63)	2.9 (.62)	F = 0.01; p = .91	
Pseudoscience Instruction group				
Paranormal***	2.3 (.76)	1.6 (.68)	F = 133.07; p < .0001	1.97
Religion***	3.0 (.99)	2.4 (1.07)	F = 78.63; p < .0001	1.52
Health***	3.4 (.67)	2.5 (.75)	F = 193.85; p < .0001	2.38
Extraordinary Life Forms***	2.5 (.89)	1.7 (.86)	F = 145.40; p < .0001	2.32
Conspiracy Theories***	2.0 (.65)	1.7 (.65)	F = 39.23; p < .0001	1.07
Ghosts***	3.0 (1.00)	2.3 (1.00)	F = 79.94; p < .0001	1.53
Total***	2.6 (.63)	2.0 (.66)	F = 233.90; p < .0001	2.62
Research Methods group				
Paranormal**	2.4 (.83)	2.3 (.83)	F = 6.57; p = .01	0.41
Religion	3.1 (.96)	3.1 (1.01)	F = 0.00; p = 1.00	
Health	3.6 (.56)	3.5 (.63)	F = 0.66; p = .42	
Extraordinary Life Forms	2.4 (.87)	2.4 (.93)	F = 0.30; p = .59	
Conspiracy Theories	2.1 (.61)	2.0 (.64)	F = 2.20; p = .14	
Ghosts**	3.2 (.95)	3.1 (.90)	F = 7.91; p = .006	0.45
Total*	2.7 (.56)	2.7 (.59)	F = 5.00; p = .027	0.35

*p < .05; **p < .01; ***p < .0001

methods group, comparison group, and pre-test IEUB belief scores, as well as the student characteristics that differed by group (gender, major, and year in school). The final model (F = 546.32, df = 2, 377, p < .0001), excluded all but the total pre-test belief score and participation in the Pseudoscience Instruction class, both of which remained independently significant.

Question 2: What Beliefs are Most Likely to be Changed?

After determining that beliefs changed only in the Pseudoscience group, we narrowed our analyses to that group, as that was the only intervention that consistently reduced epistemically unwarranted beliefs. As is illustrated in Table 4 above, the pseudoscience class reduced all types of epistemically unwarranted beliefs, and all by a substantial margin. We report standardized effect sizes (Cohen's d) in Table 4. The Health EUB subscale change has the largest effect size, moving more than two standard deviations. The Extraordinary Life Forms and Paranormal subscale changes also have very large effect sizes, moving approximately two standard deviations. The Conspiracy Theory subscale changes have the lowest effect size, moving only one standard deviation.

Another way of conceptualizing these results is to consider the individual student in the class, and the likelihood of changing his or her mind about the belief. Students in the Pseudoscience Class drastically reduced their total number of epistemically unwarranted beliefs, from a total of 10.7 (SD = 6.1) at Time 1 to a total of 5.9 (SD = 5.0) at Time 2. Repeated measures ANOVA indicated that this change was statistically significant ($F = 128.69$, $p < 0.0001$, Cohen's $d = 1.94$).

The percent of students who decreased belief in each category is reported in Table 5. Approximately half of students in the Pseudoscience Instruction group reduced belief in Health and Extraordinary Life Forms EUBs. Somewhat fewer reduced Paranormal and Ghost EUBs. Unwarranted beliefs related to Religion and Conspiracy Theories were more resistant and were reduced in a smaller proportion of students.

Finally, one might wonder if students only change their minds about the issues that were specifically and directly addressed in class, or if they can generalize what they learn to other related epistemically unwarranted beliefs and reduce belief in those too. In order to explore this question, we asked each instructor of the pseudoscience classes exactly which topics they addressed in their class. The three instructors addressed somewhat different topics in class. We calculated change scores (pre-score minus post-score) for topics covered, and for topics not covered, by each instructor. For students in the Pseudoscience Instruction group, for whom both pre- and post-test data are complete ($n = 135$) repeated measures ANOVA revealed that students reduced their belief in both covered ($F = 102.9$, $df = 1$, $p < .0001$) and not-covered ($F = 57.1$, $df = 1$, $p < .0001$) topics. A paired sample t test comparing total change scores for the covered (mean change 0.81, SD = 0.62) versus non-covered (mean change 0.49, SD = 0.46) topics revealed that students reduced belief at double the magnitude in topics actually directly addressed in class ($T = 9.64$, $df = 134$, $p < .0001$).

Question 3: Which Students are Most Likely to Change Their Beliefs?

Every teacher hopes that the material he or she teaches is equally accessible to all students in the class. However, forces outside of the classroom may predispose students either to learn, or to resist learning. We consider here their demographics (gender, race/ethnicity, age, and socioeconomic status), their beliefs (political orientation, the religiosity of their upbringing, current religious belief, and their propensity toward lifelong learning), and

Table 5 Percent of students who decreased belief

	Percent of students who decreased belief		
	Pseudoscience Instruction group	Research Methods group	Comparison group
Paranormal	39	10	9
Religion	29	6	6
Health	55	8	7
Extraordinary Life Forms	49	10	8
Conspiracy Theories	22	11	7
Ghosts	43	18	16
Total	39	3	2

academic indicators (current cumulative GPA, high school GPA, SAT scores, major, and curiosity).

We restricted these analyses to the students in the Pseudoscience Instruction group, and examined each of these variables in relationship to pre-test scores for each subscale of belief, as well as the change score for each subscale of belief. We used correlation coefficients to examine the continuous variables, and ANOVAs to explore the categorical variables. We present a summary of the findings in Table 6.

Some demographic variables were related to pre-test belief scores, but not related to change scores. Gender, race/ethnicity, and socioeconomic status were related to some pre-test belief scores such that non-White students, women, and lower SES students were more likely to believe in some of the epistemically unwarranted beliefs. The only change score related to a demographic variable was change in Conspiracy Theory EUBs, with White students being less likely to change those beliefs than Latino and Asian students. The Total EUB score reflected the general pattern, with women having higher total scores than men, with Latinos and Asians having slightly higher scores than Whites, and with age and SES being negatively correlated with total score. But change of Total EUB change score was not related to any of these demographic variables.

Ideologies were only sporadically related to pre-test beliefs and change scores. Political orientation was largely unrelated to epistemically unwarranted beliefs, except that the Religious EUB subscale scores are highest among the most politically conservative students. Childhood religiosity was not related to any belief or change scores. Current religiosity was positively correlated with Religious and Health pre-test EUBs, and positively correlated with the likelihood of changing Health beliefs. Propensity for lifelong learning was negatively correlated with Conspiracy Theory and Ghost beliefs, but not related to change scores.

Academic indicators were strongly related to pre-test belief scores, and some were also related to change scores. High school GPA, current cumulative GPA, and SAT scores were negatively correlated with most pre-test belief scores. The Honors cohort had lower levels of belief at pre-test on most subscores compared to the regular students. However, there were only two change scores that the academic indicators were related to: Health (with higher performing students having less belief to begin with, and also exhibiting a greater reduction in belief) and Conspiracy Theories (with higher performing students having less belief to begin with, but also less change). With regard to major, students in the Natural Sciences had lower belief scores to begin with in several categories, and they were the most likely to reduce belief in Health EUBs. Epistemic curiosity was unrelated either to EUBs at Time 1 or to change scores.

Overall, several student characteristics were associated with beliefs at Time 1, but very few student characteristics were associated with change scores.

Discussion

This study replicates the findings of earlier research on three points: the pervasiveness of epistemically unwarranted beliefs in college students, a dramatic reduction of those beliefs following completion of a critical thinking class that specifically and directly addresses such beliefs, and no significant reduction in belief among those in a research methods class or another comparison group class. Furthermore, this study provides new information about the beliefs for which change was most likely (Health Pseudoscience, Extraordinary Life Forms, and to a lesser degree, Paranormal EUBs and Ghosts) and least likely

Table 6 Relationship of student variables to time 1 belief and change scores in the pseudoscience instruction group

Subscale	Associated with belief at time 1	Associated with change score
Paranormal	Gender (women higher; p = .05)	None
	Race (Asian highest; p = .04)	
	SES (r = − 0.25; p = .002)	
	SAT (r = − 0.46; p < .0001)	
	HS GPA (r = − 0.20; p = .006)	
	Major (NatSci lowest; p = .027)	
	Honors (lower; p = .004)	
	Current GPA (r = − 0.25; p < .0001)	
Religion	Gender (women higher; p = .003)	None
	Race (Latino highest; p = .03)	
	Politics (conservative highest; p < .0001)	
	Current religiosity (r = 0.68; p < .0001)	
	SAT (r = − 0.25; p = .001)	
	Major (NatSci lowest; p = .014)	
Health	Current religiosity (r = .25; p < .001)	Politics (conservative most change; p = .046)
	SAT (r = − 0.30, p < .0001)	Current religiosity (r = .27; p < .003)
	Current GPA (r = − 0.16; p = .023)	SAT (r = 0.29; p = .001)
		HS GPA (r = 0.25; p = .003)
		Major (NatSci most change; p = .015)
		Honors (more change; p = .001)
Extraordinary Life Forms	Race (Latino and Asian highest; p = .03)	None
	SES (r = − 0.40; p < .0001)	
	SAT (r = − 0.37; p < .0001)	
	HS GPA (r = − 0.20; p = .005)	
	Honors (lowest; p < .0001)	
	Current GPA (r = − 0.22; p = .002)	
Conspiracy Theories	Race (Asian highest; p < .0001)	SES (r = − 0.26; p = .005)
	SES (r = − 0.44; p < .0001)	
	Lifelong learning (r = − 0.17; p = .02)	
	SAT (r = − 0.56; p < .0001)	
	HS GPA (r = − 0.35; p < .0001	
	Honors (less belief; p < .0001)	
	Current GPA (r = − 0.34; p < .0001)	
Ghosts	Gender (women higher, p = .017)	Lifelong learning (r = − 0.20; p = .024)
	Race (Latino highest; p = .01)	
	SES (r = − 0.27; p = .001)	
	Lifelong learning (r = − 0.21; p = .006)	
	SAT (r = − 0.43; p < .0001)	
	HS GPA (r = − 0.18, p = .014)	
	Major (NatSci lowest; p = .005)	
	Honors (lower; p < .0001)	

Table 6 (continued)

Subscale	Associated with belief at time 1	Associated with change score
	Current GPA (r = − 0.23, p = .001)	
Total EUBs	Gender (women higher, p = .022)	None
	Age (r = − 0.16, p = .027)	
	Race (Latino and Asian highest; p = .004)	
	SES (r = − 0.33; p < .0001)	
	Current religiosity (r = .26; p = .001)	
	Lifelong learning (r = − 0.22; p = .005)	
	SAT (r = − 0.54; p < .0001)	
	HS GPA (r = − 0.25, p = .001)	
	Major (NatSci lowest; p = .014)	
	Honors (lower; p < .0001)	
	Current GPA (r = − 0.29, p < .0001)	

(Conspiracy Theories), and a complex description of students most likely to reduce specific epistemically unwarranted beliefs after the pseudoscience class. Demographic variables, beliefs, and academic indicators were predictive of beliefs at pre-test, but not generally related to change scores.

Prevalence of Epistemically Unwarranted Beliefs

We found that students, on average, believed in somewhat more than 12 (M = 12.4, SD = 6.2) of the 37 epistemically unwarranted beliefs studied. This coincides with other research on prevalence of belief in US populations, including college students (Dyer and Hall 2015; National Science Board 2010), but that does not make it less alarming. We acknowledge that college students are subject to the same forces as the population as a whole, including the perception problems and cognitive fallacies that cause all human beings to be vulnerable to epistemically unwarranted beliefs. Students were most likely to endorse belief in health pseudoscience (e.g., chiropractic, acupuncture) and beliefs that relate tangentially to their religious beliefs (e.g., faith healing, near death experiences). We assume that health pseudoscience is a risk that they are not aware of given how mainstream these pseudoscientific practices are, so the high level of belief is not surprising. Furthermore, while the specific items on the religious belief subscale do not represent core tenets of Christianity and they are empirically testable and demonstrably without supporting evidence, their simple association with mainstream religious belief may explain their prevalence.

Furthermore, we speculate that the college environment does little to protect against such beliefs for a few reasons. First, instructors of college courses encourage students to have an open mind in order to expand their intellectual horizons. This expansion of the mind, which requires a willingness to consider ideas that are new to them, is essential to learning. It may only work if students can practice the habit of suspending judgment upon first exposure to a new idea. Therefore, if they are busy learning in college, they are likely to be practicing this skill, which may open them up to bad ideas as well as good ones.

Secondly, the college environment in one within which students must be willing to trust their professors. Professors expose them to the new ideas, and as a practical matter, students must be able to trust that they will not be led astray in a learning environment that requires them to have an open mind. They assume that their instructors are the most highly trained professionals in a given field, that they were hired only if they had demonstrated competence, and that they wield professorial power responsibly. Therefore, the authority of the professor may inadvertently discourage students from exercising skepticism.

Therefore, while universities may be places for intellectual engagement, ironically, they may not be especially good at preparing students to be skeptical of epistemically unwarranted assertions. If so, it is critically important for universities to provide direct instruction on skepticism in order to counter-balance those processes.

Critical Thinking Interventions

The results of this study suggests that college students can be helped, in a single semester course, to reduce their susceptibility to epistemically unwarranted beliefs. This is very good news for higher education. While these beliefs are widespread, they are not firmly entrenched and immutable in college students. This research also offers some guidance about how skepticism can be instilled in learners. Understanding the methods of science is not enough. Students need more direct instruction about critical thinking with respect to pseudoscience in order to apply knowledge of research methods to pseudoscience topics.

The critical thinking class studied here is offered in the College of Science and Mathematics, has a designation as a Natural Science class, and is taught by faculty from multiple departments in the college. The title is "Science and Nonsense." What all sections have in common is that they teach how to evaluate credibility of evidence, how to demarcate science from non-science, and they offer a direct juxtaposition of science against pseudoscience.

While there are surely multiple ways of teaching a class like this, this model illustrates that effective critical thinking education need not be grounded in any one specific discipline. Instead, we propose that the key to effectiveness is the direct application of the principles of science and critical thinking to specific pseudoscience topics. This is consistent with a recently published study that found identical results when the specific topics had to do with pseudohistory rather than pseudoscience; it was only the explicit instruction with real examples that produced a reduction of EUBs (McLaughlin and McGill 2017). This should not be a surprise to educators. Application of knowledge involves skills obtained through practice, and good pedagogy must provide opportunities for students to exercise new skills.

Therefore, institutions of higher learning should consider requiring their critical thinking general education courses to specifically address epistemically unwarranted beliefs. Such beliefs exist in all disciplines, so this requirement could be met by a wide variety of critical thinking classes offered by any department or program. But assuming that students will be able to generalize learning enough to apply it to detect fraud and faulty logic is a wrong assumption. It may be that academia creates a context within which students grow reliant on the expertise of the academy, and are not inclined to consider the possibilities of fraud or faulty logic. General education curricula should explicitly teach students how to think about these possibilities.

That being said, once students in this study were introduced to pseudoscience, they showed some ability to generalize their critical thinking skills. They did grow significantly

skeptical of topics that were not explicitly addressed in their pseudoscience class, although the effect was not as great as the effect on topics directly addressed in class. This is exactly what one would expect a novice to do with brand new information, to apply it tentatively. This reflects exactly the desired outcome of a critical thinking class.

We caution the reader, however, to note that there may be a selection bias, such that students who are already somewhat skeptical already elect to take a course entitled "Science and Nonsense" as opposed to other options available in the Critical Thinking area. This may exaggerate the effect of the course because the subjects are open to exploring the topic. However, the bias could work in the opposite direction. Since students in this class had lower belief scores to begin with, they essentially had less room for improvement. But despite this handicap, they demonstrated more improvement than the other groups. This is striking.

What Changes, and Who Changes

With regard to beliefs most changed by the intervention, this research found that students who participated in this Pseudoscience Instruction class reduced belief in areas that are central to identity (e.g., health beliefs) not just those topics that are curiosities (e.g., extraordinary life forms, paranormal). We have identified health pseudoscience as the most potentially impactful for the well-being of society, so the very large effect in this area is encouraging.

The area of most change was indeed Health Pseudoscience beliefs. Health pseudoscience is particularly problematic for society, due to the health and financial consequences of believing unsubstantiated claims. For instance, the 2015 measles outbreak in the United States shed light on the danger of the anti-vaccination movement's rejection of science. Therefore, a reduction of belief in this area is especially beneficial for individual students and for society at large.

The area of least change was belief in Conspiracy Theories. This is the area, other than health, about which we are most concerned due to the societal impact of these beliefs. However, the very nature of a conspiracy theory is to mistrust authorities and official sources of information. Therefore, it is not surprising that such beliefs are difficult to change. However, their prevalence is low compared to the other EUBs studied here, so there was not a lot of room for reduction. It may be that the mechanism for reducing belief in Conspiracy Theories will be different from pedagogies that reduce other types of unwarranted beliefs.

Academic indicators (that may be proxies for intelligence) were negatively correlated with pre-test belief, but only sometimes positively correlated with the reduction of epistemically unwarranted beliefs. Demographic variables (such as gender and race/ethnicity) were related to pre-test beliefs, but not generally related to the likelihood of changing beliefs. Political affiliation and curiosity were completely unrelated to belief or change in belief. The effects of religious training in childhood and current religious belief were remarkably narrow. Natural science majors were the most likely to reduce belief in Health Pseudoscience.

The overall pattern here is that all students who received the pseudoscience instruction were likely to reduce epistemically unwarranted beliefs, not just those with a specific profile. This is good news for educators. This intervention has the potential to reach all students. This speaks loudly to the appropriateness of a general education requirement for critical thinking education specifically targeting pseudoscience. This is an

intervention that can benefit all students equally, and thus, can potentially improve our society by protecting its members, even its most vulnerable members, from deception.

Previous studies have only investigated the students of a single instructor, and that is usually the instructor who is also the researcher. The current study, however, investigated all sections of a given course, including three different instructors, only one of whom is a researcher/author on this paper. We found that there were statistically significant reductions in belief among students of all three of these instructors. It is only the approach of the course that they have in common, not the specific content and not the charisma or energy of a specific instructor. This is evidence that the approach described here is generalizable.

Limitations and Future Directions

While the findings of this research are robust and encouraging, this is observational research with some limitations due to the design. Specifically, the three intervention groups were different from each other. We cannot be certain that the changes in the Pseudoscience Instruction group are due to the instruction, and not due to the fact that the students in that group were more likely to be White, male, Natural Science majors, and somewhat more skeptical to begin with. The multiple regression analysis indicates that these factors are not critical, but potential multicollinearity complicates interpretation of the statistical analysis.

We acknowledge the possibility that demographics drive the group differences, but argue that it is unlikely for two reasons. First, the effect sizes in the intervention group were very large, so the magnitude of the effect is compelling. These are not marginally significant effects produced by a large sample size. These are big reductions in belief that happened only in one group. Second, if these demographic factors drove the effect, we would have expected to see within-group variation to reflect this as well, and it is simply not there. Within the intervention group, we did not see differences by gender, race, and major.

Therefore, we suspect that explicit pseudoscience instruction really does reduce epistemically unwarranted beliefs. We hope that this is confirmed by future replications of this research. Further research should explore the pedagogy of critical thinking classes such as this one in order to identify those strategies that are most effective.

Conclusion

This study contributes to a growing body of literature on higher education designed to improve critical thinking among college students. Critical thinking education certainly must include an element of information literacy to help students know where to find answers to questions relevant to their lives, and how to appraise those sources. As information has grown more abundant and accessible, students (and all of us) must have skills with which to appraise the information that they encounter. As this research demonstrates, they encounter a lot of nonsense, and a lot of untested, and untestable, assertions. It is absolutely essential, for their health and wealth, that they be equipped with the tools necessary to protect themselves.

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