Confidence without Competence in the Evaluation of Scientific Claims

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Abstract

Scientific entities like X-rays and black holes defy firsthand observation and everyday intuition, yet most people outside the scientific community still believe in their existence. Upon what kind of epistemic foundations do such beliefs rest? The present study explored this question by comparing students' scientific beliefs to their supernatural beliefs along four dimensions of epistemic import: confidence, perceived consensus, means of justification, and openness to revision. Participants' scientific beliefs were strongly differentiated from their supernatural beliefs along the dimensions of confidence and consensus but only weakly differentiated along the dimensions of justification and revision. Moreover, participants' confidence in both types of beliefs was predicted by their consensus estimates but not their ability to cite evidence in support of, or potentially in conflict with, those beliefs. These findings imply that students' scientific beliefs are no more epistemologically sound than their supernatural beliefs, despite self perceptions to the contrary.

Keywords: Belief; testimony; naïve epistemology; intuitive theories; science education; conceptual development

Introduction

Research in cognitive science has informed the goals and methods of science education in a number of ways. Research on intuitive theories, for example, has clarified the nature of students' pre-instructional conceptions and the process by which those conceptions may be replaced by more accurate, scientific ones (Carey, 2009; Vosniadou, 1994). Research on knowledge representation has highlighted strategies effective at promoting conceptual change in the science classroom (Ohlsson, 2009; Slotta & Chi, 2006). And research on causal inference has shed light on how our theoretical commitments influence, and are influenced by, the interpretation of empirical data (Chinn & Brewer, 2001; Schulz, Goodman, Tenenbaum, & Jenkins, 2008).

To date, such research has focused mainly on the *understanding* of scientific claims, yet an equally important issue in the realm of science education is the *acceptance* of such claims as true. What, for instance, leads a student to accept the existence of electrons given that electrons are neither observable (with the naked eye) nor intuitive (with respect to our everyday conceptions of matter)? This issue is particularly important in domains where scientific explanations compete with supernatural explanations of the same phenomena, like explanations for the origin of species or explanations for the origin of the universe.

Various attempts to articulate the difference between scientific explanations and supernatural explanations have focused on differences in evidential structure (e.g., only scientific explanations generate testable hypotheses) or evidential support (e.g., only scientific explanations are supported by observation and experimentation), yet, from the perspective of how scientific explanations are *learned*, these criteria are not particularly salient. Students of science are not, after all, practitioners of science, and it is thus unlikely that most students appreciate differences in the *derivation* of scientific and supernatural explanations when simply presented with the explanations themselves.

Indeed, the *products* of science and religion – i.e., concepts, theories, explanations, and assertions – share many commonalities even if the *practices* of science and religion do not (McCauley, 2000). Both provide frameworks for interpreting everyday observations and experiences. Both posit unobservable entities as the causes of various observable phenomena. And both extend, or even defy, early-developing intuitions about the kinds of entities that exist and the kinds of interactions those entities engage in.

Given such similarities, it is unclear how well students differentiate the epistemic status of scientific claims from that of supernatural claims. Although no studies have addressed this question directly, extensive research on students' understanding of scientific inquiry provides reason to suppose that most students are not equipped to make such a differentiation (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Schauble, Glaser, Duschl, Schulze, & John, 1995; Smith, Maclin, Houghton, & Hennessey, 2000). This research has shown that students typically conceive of science as problem solving, rather than inquiry, and typically conceive of experiments as means of confirming, rather than testing, one's ideas. Even individuals who hold doctorates in the humanities tend to believe (a) that scientists abide by a single, deterministic method of inquiry, (b) that scientists conduct experiments in order to prove (rather than support) their ideas, (c) that scientists deduce (rather than infer) their ideas from the data at hand, and (d) that scientists who study the same data will inevitably arrive at the same conclusions (Lederman et al., 2002).

The present study attempted to extend this literature by exploring students' epistemic commitments regarding the products of science, rather than its methods. These commitments were assessed in relation to commitments regarding beliefs with ostensibly inferior evidential support – i.e., supernatural beliefs. Four dimensions of students' epistemic commitments were measured: (1) confidence in the validity of one's beliefs, (2) perceived consensus surrounding the endorsement of one's beliefs, (3) means of justifying one's beliefs, and (4) openness to revising one's beliefs. Of primary interest was the extent to which the first dimension (confidence) was related to the other three (consensus, justification, and revision).

Method

Participants

One-hundred and forty college undergraduates participated in the study for course credit in an introductory psychology class. Approximately half were recruited from a large, urban university in the Northeastern US and half from a small, urban college in the Southwestern US. Preliminary analyses revealed no significant differences between the two groups on any of the findings reported below, so they were pooled.

In the course of the study, participants rated their belief in the existence of six scientific entities and twelve supernatural entities. Although all participants endorsed the existence of at least three scientific entities, 31 participants did not endorse the existence of at least three supernatural entities. Those 31 were excluded from the analyses presented below, as they provided no internal metric against which to compare their scientific beliefs. The final sample thus consisted of 106 participants who endorsed the existence of supernatural entities at a frequency similar to the general public (Moore, 2005; Winseman, 2004).

Procedure

Participants completed a questionnaire that probed their beliefs about black holes, electrons, evolution, fluoride, genes, X-rays, angels, fate, ghosts, God, Heaven, Hell, karma, precognition, reincarnation, Satan, souls, and telepathy. Pilot data confirmed that, given this selection, college students tended to endorse an equal number of scientific and supernatural entities (i.e., all six scientific entities and around six of the twelve supernatural ones).

For each entity, participants were asked five questions: (1) whether they currently believed in the entity's existence; (2) how confident they were of that belief (on a scale from 1 to 7); (3) how many other Americans (out of 7) hold the same belief; (4) why they believed the entity exists; and (5) what evidence might persuade them to change their mind. Responses to these questions will henceforth be referred to as "existence judgments," "consensus estimates," "belief justifications," and "belief refutations," respectively.

Participants' belief justifications and belief refutations were analyzed using coded schemes described below. These schemes were constructed via a bottom-up process in which one-third of the data were sorted into numerous, fine-grained categories closely resembling the data themselves. Those categories were then collapsed into eight "basic-level" categories, which, in turn, were collapsed into three "superordinate" categories. These coding schemes were then applied to the entire dataset by two independent coders: the author, who created the coding schemes, and a research assistant, who was instructed on how to apply the coding schemes but was not involved in their creation. Among basic-level categories, agreement between coders was 90% for belief justifications and 89% for belief refutations. Among superordinate categories, agreement was 95% for belief justifications and 94% for belief refutations. Disagreements were resolved through discussion.

Results

Existence Judgments

The first question participants answered about each entity was whether or not they believed in its existence. "Yes" responses were assigned 1 point, and "No" responses were assigned 0 points. Participants' mean existence judgments are displayed in Table 1. On average, participants endorsed the existence of 5.9 scientific items (or 98%) and 7.6 supernatural items (or 63%). Item for item, these judgments were highly similar to those obtained in national surveys of supernatural belief (e.g., Moore, 2005; Winseman, 2004).

It should be noted that subsequent analyses were conducted *only* on responses connected with entities judged existent by the responder. Responses connected with entities judged nonexistent were excluded from the dataset, as they were not directly relevant to the question of how the *acceptance* of scientific claims compares to the *acceptance* of supernatural claims. Thus, the mean confidence ratings and mean consensus estimates reported in Table 1 represent only those participants who judged the target entity existent.

Table 1: Mean existence judgments (range = 0 to 1), confidence ratings (range = 1 to 7), and consensus estimates (range = 1 to 7) for the six scientific entities (top) and twelve supernatural entities (bottom).

Item	Existence	Confidence	Consensus
X-rays	1.00	6.9	6.4
Genes	.99	6.8	6.4
Electrons	.99	6.4	5.9
Fluoride	.98	6.7	6.3
Evolution	.95	6.3	4.7
Black holes	.94	5.7	5.1
Souls	.97	6.0	5.4
God	.83	5.9	5.2
Karma	.78	5.6	4.0
Heaven	.75	5.6	5.2
Angels	.66	5.4	3.9
Fate	.66	5.4	4.5
Ghosts	.56	4.6	3.6
Hell	.52	5.1	4.7
Precognition	.51	4.9	3.0
Telepathy	.44	4.7	3.0
Satan	.41	5.8	4.5
Reincarnation	.40	4.9	3.0

Confidence Ratings

Participants rated their confidence in the existence of each entity on a scale from 1 ("no confidence") to 7 ("100% confident"). Participants tended to be highly confident, selecting "7" significantly more than any other rating (33% of all selections, binomial $p < 0.001$). They also exhibited greater confidence in their existence judgments for scientific items than those for supernatural items, as shown in Table 1. Not only was the mean rating for the scientific items

significantly greater than that for the supernatural items when averaged across entities (M = 6.5 vs. M = 5.3, $t(108)$ = 11.30, $p < 0.001$), but the mean ratings for individual scientific items were almost always greater than the mean ratings for individual supernatural items. Interestingly, the more often an entity was judged existent by the group, as a whole, the more confident any individual participant was in his/her judgment. Indeed, the correlation between mean existence judgments and mean confidence ratings (i.e., columns 2 and 3 of Table 1) was highly significant ($r(18)$ = 0.85, $p < 0.001$), implying that participants' confidence in their existence judgments may have been influenced by their perception of how frequently others would agree with them.

Consensus Estimates

After selecting a confidence rating, participants estimated the number of Americans who would agree with their existence judgment on a scale from 1 ("1 out of 7") to 7 ("7 out of 7"). Mean consensus estimates for each entity are displayed in Table 1. Similar to the confidence ratings, consensus estimates for the scientific items were, on the whole, significantly greater than those for the supernatural items (M = 5.8 vs. M = 4.3, $t(108)$ = 16.80, $p < 0.001$). Participants' mean consensus estimates were also correlated with their mean existence judgments, when compared on an item-by-item basis ($r(18)$ = 0.84, $p < 0.001$), indicating that their estimates were at least partly veridical.

Belief Justifications

Participants provided a total of 1458 justifications for their existence judgments (639 for scientific items and 819 for supernatural items). These responses were sorted into the various categories and subcategories described below.

Evidential Justifications These justifications referenced objectively verifiable facts that support the existence of the entity in question. Evidential justifications came in two forms: appeals to direct evidence and appeals to indirect evidence (which accounted for 4% and 13% of all justifications, respectively). Appeals to direct evidence described an observable property or causal effect of the target entity (e.g., evolution must exist because "there are fossils for past species that have similar characteristics to present day animals;" genes must exist because "they can be sequenced and manipulated"). Appeals to indirect evidence referenced facts about the world consistent with the existence of the target entity but *not inconsistent* with other explanations (e.g., genes must exist because "children look like their parents;" God must exist because "some force must explain the Universe"). It should be noted that while it was not possible for participants to cite direct evidence of supernatural entities, it was possible for them to cite indirect evidence, and many did. It should also be noted that evidential justifications were the only justifications that could be considered epistemologically sound, as they were the only justifications that provided a *warrant* for belief rather than merely a *reason* for belief.

Deferential Justifications These justifications referenced the source of one's belief without referencing any factual or conceptual considerations relevant to the legitimacy of that source. These justifications came in three forms: appeals to unspecified evidence, appeals to authority or instruction, and appeals to a preexisting worldview or commitment (which accounted for 15%, 13%, and 23% of all justifications, respectively). Appeals to unspecified evidence differed from appeals to direct or indirect evidence in that they lacked any description of the evidence itself (e.g., X-rays must exist because "there is scientific evidence proving their existence;" souls must exist because "aspects of the concept have been sort of proven"). Appeals to authority/instruction referenced a trusted source of information without providing any details regarding the content of that information (e.g., black holes must exist because "I trust my physics teacher Mr. Murray;" Hell must exist because "it's in the Bible"). Finally, appeals to a worldview/commitment referenced some preexisting philosophy or creed consistent with the existence of the entity in question (e.g., fluoride must exist because "I'm a chemistry major;" angels must exist because "I'm Muslim; angels exist by default"). Like appeals to authority/ instruction, appeals to a worldview/commitment contained no factual information from which the belief could be inferred by someone who did not share the participant's same cultural or educational background.

Subjective Justifications These justifications referenced considerations predicated on a participants' own experience or point of view. They included appeals to intuition or volition, appeals to a personal experience or encounter, and appeals to definitions or clarifications (which accounted for 15%, 11%, and 6% of all justifications, respectively). Appeals to intuition/volition referenced the sensibility, plausibility, or desirability of the target entity without referencing considerations that actually bear upon its existence (e.g., electrons must exist because "they make rational sense;" Heaven must exist because "I like to think that my loved ones are going there"). Appeals to experience/ encounters took the form of autobiographical events whose interpretation presupposed the existence of the entity in question (e.g., fluoride must exist because "it has been used on my teeth;" telepathy must exist because "my sister and I used to have it a lot when we played 21 questions"). Finally, appeals to definitions/clarifications were intended to refine the scope or certainty of one's belief, which, like the other two subtypes, provided no objectively persuasive reasons for belief (e.g., "I believe that organisms adapt to their environment, but not that we all come from one common being;" "I believe in the presence of those who have passed away, and I suppose this is what you would call an angel").

Justifications Frequencies by Domain The proportion of justifications that fell into each of the above categories are displayed in Table 2. Paired-samples t tests revealed that participants provided significantly more deferential

justifications for scientific items than for supernatural items ($t(108) = 2.61$, $p < 0.05$) and significantly more subjective justifications for supernatural items than for scientific items ($t(108) = 8.02$, $p < 0.001$). Participants also provided significantly more evidential justifications for scientific items than for supernatural items ($t(108) = 6.75$, $p < 0.001$), but the magnitude of this difference was small (0.16), especially considering the fact that one subtype of evidential justifications – appeals to direct evidence – could be provided only for scientific items.

In sum, participants provided similar, yet non-identical, justification profiles across the two domains of belief. Although participants provided significantly more evidential justifications for their scientific beliefs than for their supernatural beliefs, they provided relatively few evidential justifications overall. Instead, they relied predominantly on deferential justifications in both domains, appealing to a trusted source of information (e.g., "my teacher," "my textbook," "my religion," "scientists," "the Bible") rather than the information itself.

Table 2: Mean proportion of justifications in each domain representative of each justification type (+ *SE*).

Justification type	Scientific	Supernatural
Evidential	.28 (.02)	.11 (.02)
Deferential	.54 (.02)	.47 (.03)
Subjective	.18 (.01)	.42 (.03)

Belief Refutations

The final question participants answered for each entity was what evidence would persuade them to change their mind about its existence. These responses are described below.

Evidential Refutations Refutations of this nature cited substantive facts or ideas that challenged the belief in question. Two subtypes were observed: anomalous data and alternative explanation (which accounted for 7% and 13% of all refutations). Participants who cited anomalous data described findings or phenomena that, if discovered, would be inconsistent with the target entity's existence (e.g., one's belief in electrons would be challenged "if an atom was found without them;" one's belief in karma would be challenged "if bad people started experiencing good things"). Participants who cited alternative explanations described situations in which the target entity would no longer be needed to explain the phenomena it was intended to explain (e.g., one's belief in fluoride would be challenged "if a new scientific model was heavily endorsed that could explain the building blocks of life without using the elements in the periodic table;" one's belief in souls would be challenged "if science could find a way to explain why there is life at all and how individuality is created in terms of thinking and feeling"). Just as evidential justifications were the only epistemologically sound type of justification, evidential refutations were the only epistemologically sound type of refutation.

Deferential Refutations These refutations fell into the same categories as deferential justifications: appeals to unspecified evidence, appeals to authority or instruction, and appeals to a preexisting worldview or commitment (which accounted for 22%, 6%, and 3% of all refutations, respectively). Appeals to unspecified evidence acknowledged that one's belief was revisable in light of new evidence but did not specify the content of that evidence (e.g., one's belief in genes would be challenged by "scientific evidence that can prove genes do not exist;" one's belief in precognition would be challenged by "proof that it's genuinely impossible"). Appeals to testimony/education cited an informant, or group of informants, whose change of mind was sufficient to incite a personal change of mind (e.g., one's belief in X-rays would be challenged "if a bunch of scientists got together and proved they didn't exist;" one's belief in Satan would be challenged "if the Church said it did not exist"). Finally, appeals to a worldview/commitment cited the possibility of changing a fundamental belief, or system of beliefs, that would result in a change to the specific belief at hand (e.g., one's belief in evolution would be challenged by "becoming extremely religious;" one's belief in reincarnation would be challenged by "more exposure to alternative beliefs"). All three categories cohered in their privileging of information sources over the information itself.

Subjective Refutations These refutations referenced considerations relevant only to the participant. They included appeals to a personal experience or encounter, appeals to ignorance or uncertainty, and denials of the premise itself (which accounted for 9%, 10%, and 30% of all refutations, respectively). Participants who appealed to a personal experience/encounter described hypothetical events that, if experienced, would call the target entity's existence into question (e.g., one's belief in X-rays would be challenged "if I found out all the X-rays I underwent were staged;" one's belief in Hell would be challenged "if I died and wasn't punished for all my sins"). Participants who appealed to ignorance/uncertainty explicitly claimed not to know what would constitute counterevidence to the entity's existence (e.g., "I don't know if you could ever prove it or disprove it;" "it is a personal belief, so I am not sure"). Finally, some participants denied the premise that their mind could be changed altogether, asserting that target entity's existence was irrefutable (e.g., "there is no evidence that could effect my belief in fate;" "Nothing at this point can dissuade me from the idea of evolution"). While denying the possibility of counterevidence is, of course, different from identifying counterevidence contingent on one's own experience, such responses were still fundamentally subjective in that they focused on personal predilections rather than external information (evidential refutations) or information sources (deferential refutations).

Refutation Frequencies by Domain Table 3 displays the mean proportion of evidential, deferential, and subjective

justifications to total justifications in each domain. Similar to the findings regarding belief justifications, participants provided significantly more deferential refutations for scientific items than for supernatural items ($t(108) = 4.80$, $p < 0.001$) but provided significantly more subjective refutations for supernatural items than for scientific items ($t(108) = 8.06$, $p < 0.001$). Participants also provided significantly more evidential refutations for scientific items than for supernatural items ($t(108) = 4.38$, $p < 0.001$), but the magnitude of this differences was, once again, quite small (0.11). Thus, just as participants tended to cite non-evidential considerations in justifying their scientific beliefs, they tended to cite non-evidential considerations when contemplating the revisability of those beliefs.

Table 3: Mean proportion of refutations in each domain representative of each refutation type (+ *SE*).

Refutation type	Scientific	Supernatural
Evidential	.29 (.02)	.19 (.02)
Deferential	.39 (.03)	.21 (.02)
Subjective	.32 (.02)	.59 (.03)

Interrelations among the Four Indices of Belief

The analyses presented thus far indicate that the epistemic foundations of participants' scientific beliefs are not identical to those of their supernatural beliefs. As a group, participants (a) exhibited greater confidence in their scientific beliefs; (b) perceived greater consensus surrounding their scientific beliefs; (c) cited more evidence in support of their scientific beliefs; and (d) identified more counterevidence to their scientific beliefs. This pattern of results appears, on its surface, to imply that participants' scientific beliefs were more epistemologically sound than their supernatural beliefs. Nevertheless, three additional findings militate against this interpretation.

First, the degree of differentiation between participants' scientific and supernatural beliefs was much greater along some dimensions than others. Cohen's *d* for the difference between scientific and supernatural beliefs was 1.41 for the confidence ratings and 1.64 for the consensus estimates, but was only 0.61 for participants' tendency to provide evidential justifications and 0.36 for participants' tendency to provide evidential refutations. Apparently, participants' sensitivity to differences between scientific and supernatural beliefs influenced their appraisals of confidence and consensus much more than it influenced their ability (or proclivity) to cite evidential considerations relevant to those beliefs.

Second, differences in confidence were not warranted by differences in the quality of participants' justifications or refutations. This finding emerged from a hierarchical regression analysis in which participants' confidence ratings for the scientific items were first regressed against their consensus estimates (Model 1) and then regressed against their tendency to provide (a) evidential justifications and (b) evidential refutations (Model 2). While the first model explained a significant amount of the variance in participants' confidence ratings ($R^2 = 0.12$; *F-change* $(1,637) = 89.63$, $p < 0.001$), the second model did not ($R^2 = 0.13$; *F-change* $(2,635) = 1.75$, *ns*). Thus, participants' confidence in their scientific beliefs was linked to their perception of how widely those beliefs are shared but was not linked to their ability to support those beliefs with evidence.

Third, the ability to provide evidential justifications and evidential refutations was not widespread. Only 13 participants (or 12%) provided evidential justifications as their modal justification type, and only 19 participants (or 17%) provided evidential refutations as their modal refutation type. Moreover, participants' tendency to provide evidential justifications was significantly correlated with their tendency to provide evidential refutations, as shown in Table 4. These tendencies were linked not only within the same domain but across domains as well, implying that they represent a domain-general disposition to reflect upon the validity of one's beliefs, similar to those documented in the domains of argumentative reasoning (Kuhn, 1991), inferential reasoning (Stanovich & West, 1998), and modal reasoning (Shtulman, 2009).

Table 4: Correlations between evidential justifications (JUS) and evidential refutations (REF) for both scientific items (SCI) and supernatural items (SUP).

Measure	JUS_SCI	JUS_SUP	REF_SCI	REF_SUP
JUS_SCI	1.0	.26**	.44**	.25*
JUS_SUP		1.0	.20*	.23*
REF_SCI			1.0	.43**
REF_SUP				1.0

Discussion

The evidential support for scientific claims is quantitatively and qualitatively superior to that for supernatural claims, yet it is unclear whether students appreciate this difference in light of the fact that both types of claims are conveyed in similar ways (through testimony) and perform similar functions (explaining observed phenomena in terms of unobservable entities). The present study addressed this issue by comparing students' scientific beliefs to their supernatural beliefs along four dimensions of epistemic import: confidence, consensus, means of justification, and openness to revision. Although participants were almost always more confident in their scientific beliefs than their supernatural beliefs, they were rarely able to identify evidence that might bear on the validity of those beliefs, either in the form of justification or refutation. Moreover, participants' confidence was related to their perception of how likely other people would agree with their beliefs but was *not* related to their ability to cite evidential considerations relevant to those beliefs.

Two features of the data were particularly notable. First, participants' modal form of justification was deference to the opinions and conclusions of others. That is, participants

were more likely to reference the *proximal* source of their beliefs (i.e., the testimony of an accepted authority or the tenets of an accepted worldview) than to reference its *distal* source (i.e., reasons for accepting the testimony/tenets as true), both for scientific beliefs and supernatural beliefs. Although it could be argued that deference to "more knowledgeable others" is a generally rational course of action (Keil, Stein, Webb, Billings, & Rozenblit, 2008), this claim is undermined, at least in the present study, by the fact that participants deferred to unsubstantiated sources of information (i.e., those propounding supernatural claims) as often as they deferred to substantiated ones (i.e. those propounding scientific claims). Moreover, participants who provided deferential justifications for their scientific beliefs, rather than evidential ones, also tended to claim that these beliefs were indefeasible, which clearly indicates a non-rational view of the nature of science. Indeed, the majority of participants (55%) denied that *anything* could dissuade them of the existence of at least one scientific entity.

Second, the findings obtained here with adults who had had multiple years of science instruction strongly mirror those obtained by Harris, Pasquini, Duke, Asscher, & Pons (2006) with individuals who had had little to no science instruction: 5- to 6-year-old children. In that study, children not only endorsed the existence of scientific entities, like germs and oxygen, more often than they endorsed the existence of supernatural entities, like God and the Tooth Fairy, but also claimed that more people, in general, believe in the existence of the former than the latter. They did *not*, however, provide different types of justifications for their judgments. Instead, they tended to appeal to generalizations that presupposed the target entity's existence in both cases (e.g., germs exist because "animals can have germs;" the Tooth Fairy exists because "she visits you when you lose a tooth"). While it is unclear how the justification categories used in Harris et al. (2006) relate to those used in the present study, it is telling that even young children appear to be more sensitive to the amount of consensus surrounding various extraordinary claims than to the conceptual and/or evidential status of those claims.

Taken together, these findings imply that students' understanding of science as a body of knowledge is not much better than their understanding of science as a method of inquiry (Lederman et al., 2002; Schauble et al., 1995; Smith et al., 2000). Just as students conceive of science as problem solving rather than inquiry, they justify their scientific beliefs with appeals to intuition and authority rather than evidence. And just as students think that scientists are in the business of "proving their ideas true," they think that certain scientific entities have been proven to exist beyond a shadow of doubt. These findings not only complement existing findings on students' scientific epistemologies but also point to the possibility that misconceptions about the *process* of science may actually be responsible for misconceptions about the *products* of science. Still, the question of whether, and how, such misconceptions are related awaits further research.

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