Using Neuromyths to Explore Educator Cognition: A Mouse-Tracking Paradigm

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Abstract

Current theories of knowledge acquisition suggest that newly learned knowledge does not always supplant prior knowledge, even when newly learned knowledge repairs errors. New knowledge may suppress prior knowledge, particularly for overlearned, explicit responses, creating internal competition between knowledge elements. Competition between new and prior knowledge may be one reason misconceptions are highly resistant to repair. The present study examines misconceptions in a specific domain: pre-service educators' beliefs about neuromyths. Addressing misconceptions in pre-service educators is important because these misconceptions are likely to be transmitted to students and may reduce the effectiveness of instruction. A computer mouse-tracking paradigm measured *explicit* beliefs in neuromyths as well as *implicit* uncertainty during the decision-making process. The findings demonstrated that pre-service educators often endorsed neuromyths but were uncertain about the veracity of neurofacts. These findings add to our knowledge of misconceptions, their durability, and demonstrate a need to address misconceptions in educator preparation.

Keywords: misconceptions; education; neuromyths; computer mouse tracking; knowledge acquisition; educator cognition

Introduction

Current theories of knowledge acquisition suggest that misconceptions (i.e., beliefs contrary to established evidence) about science do not disappear with the addition of new, correct knowledge. Instead, prior knowledge, including misconceptions, and newly learned knowledge coexist (Shtulman & Valcarcel, 2012). This coexistence creates the potential for interference between new knowledge and prior knowledge -- even when the prior knowledge has been overlearned (Pashler, Rohrer, Cepeda, & Carpenter, 2007). Evidence for interference emerges from studies that measure both explicit and implicit responses, demonstrating that suppressed knowledge might continue to influence behavior. The current study explores this possibility by investigating neuromyths, a subset of misconceptions about the brain and its relation to development and learning. Sampling pre-service educators, we investigate the explicit and implicit cognitive processes underlying educator cognition in an attempt to better understand why neuromyths are propagated and how knowledge interference increases misconceptions' resistance to change.

Misconceptions about science

Misconceptions may be very difficult, if not impossible, to eradicate (Goldberg & Thompson-Schill, 2009; Gregg, Winer, Cottrell, Hedman, & Fournier, 2001). Theories regarding changes in knowledge suggest the introduction of new knowledge *could* replace or dramatically restructure existing knowledge (e.g., Chi, 1994). However, an alternative theory suggests previously held knowledge is supplemented, rather than replaced, with new knowledge as it enters the system (Vosniadou, 2012). When knowledge is supplemented, internal competition may occur between new and existing knowledge if the new does not neatly align with the existing, thus requiring certain knowledge to be inhibited in favor of another. From a broad view of misconceptions, it is more likely that an additive process occurs when attempting to update prior knowledge (Shtulman, 2017).

Shtulman and Valcarcel (2012) demonstrated competition between new and prior knowledge by asking introductory psychology undergraduates to evaluate statements about the natural world. Some statements were linked to previous misconceptions (e.g., "Water kills germs."), and others were not (e.g., "Heat kills germs."). Response times were longer when the statement was linked to a previous misconception relative to those that were not, indicating the previous misconception -- or prior knowledge -- interferes with the evaluation of factual statements. This finding suggests that even when correct knowledge is acquired, incorrect prior knowledge may persist.

Therefore, the interference between new and prior knowledge may prevent the development of more accurate mental models of scientific principles and explanations (Carey, 1986). Even expert scientists may experience interference when concepts compete for activation. For instance, Masson, Potvin, Riopel, and Foisy (2014) found science experts showed greater blood flow to brain regions associated with conflict monitoring and inhibition when responding to scientifically challenging questions than science novices, suggesting neurological evidence for interference. Thus, it may be possible to *inhibit* misconception endorsement but not eliminate misconceptions.

Educator cognition & misconceptions

One class of misconception that is particularly relevant to education is neuromyths. Neuromyths (e.g., existence of learning styles) may originate from a variety of sources including broad generalization, oversimplification, and/or distortion of scientific findings (Howard-Jones, 2014; Macdonald et al., 2017; Pasquinelli, 2012), which may be further exacerbated by popular media's attempt at reaching a wider audience by sensationalizing science (Beck 2010). Prior work has clearly documented practicing educators', as well as graduate and undergraduate pre-service educators', *explicit* endorsement of neuromyths (~50%; Canbulat & Kiriktas, 2017; Dekker et al., 2012; MacDonald et al., 2017; Papadatou-Pastou, Haliou, & Vlachos, 2017). Such findings are not surprising given that most educators have limited training in critical analysis of scientific research (Ansari & Coch, 2006). Nonetheless, educators make instructional decisions every day in an effort to provide a high-quality education for every student.

These decisions are informed by explicit beliefs, often derived from formal training in subject-content and pedagogical knowledge that is gathered during educator-preparation programs (Preston, 2017). However, the knowledge guiding educators' explicit decisions is not always accurate (Pashler, McDaniel, Rohrer, & Bjork, 2008), meaning misconceptions have the potential to drive decision making within the classroom. For instance, neuromyth-based lesson plans (e.g., teaching to a learning style), curricula, or products may be deleterious to student learning and can take valuable resources (e.g., school-district dollars) and time away from evidence-based programming (Pashler et al., 2008). This concern is heightened within the current educational model in which educators are tasked with covering increasingly more content in less time (Fox, 2018). Thus, any time spent using explicit neuromyth-backed practices is creating opportunity for unintentional, but problematic, constraints on learning and development (Pashler et al., 2008).

Given the sheer amount of literature acknowledging explicit endorsement of neuromyths in the educational community, attention should consequently turn to investigating *implicit* processes associated with neuromyths. No work, to the authors' knowledge, has examined educators' (pre- or in-service) implicit decisions derived from neuromyths. Educators' implicit decisions are important to investigate, as they have the potential to affect students' learning outcomes just as explicit decisions can. Consider the negative effect math-anxious female educators can have on female students' math achievement (Beilock, Gunderson, Ramirez, & Levine, 2009) or the consequence of implicit attitudes toward certain racial or religious groups. For example, students of color are more often sent to the principal's office for subjective infractions (e.g., disrespect); whereas, white students are more often sent for objective infractions (e.g., vandalism) (Skiba, Michael, Nardo, & Peterson, 2002). These implicit beliefs can affect educators' decision making within the classroom and consequently, could limit opportunities for students to accumulate accurate knowledge. Thus, understanding educators' implicit beliefs regarding the brain and its role in learning has both practical and theoretical value, especially considering not all decisions made by educators are empirically-backed (Pashler et al., 2008).

Educators' explicit and implicit beliefs about neuro-statements can have a multiplicative effect in which science misconceptions are not only taught, but also adopted by the general public as students exit the education system. Thus, educators' beliefs have the potential to multiply and transition to systemic beliefs, as children being taught via neuromyth-backed ideology grow into adults who maintain neuromyth ideology, causing the perpetuation of scientific misconceptions. Consequently, understanding educators' explicit and implicit beliefs is of value to education and cognitive science, as neuromyths can pose a barrier to the accumulation of knowledge backed by empirical evidence. The earlier cognitive scientists can intervene in knowledge development, the less likely it becomes that learners accept misconceptions -- neuromyth or otherwise (e.g., Kelemen, Emmons, Schillaci, & Ganea, 2014).

Current Study

The present study is a conceptual replication and extension of Macdonald et al. (2017). It examines neuromyths, a subset of misconceptions related to the mind, brain, and learning (replication), using a computer mouse-tracking paradigm (extension). Computer mouse tracking reveals the "mind in motion," as parallel processes of cognition unfold over time to reflect implicit (early, heuristic) and explicit (late, systematic) processes (McKinstry, Dale, & Spivey, 2008). Examination of both explicit and implicit processes is important because it is currently unclear how cognition of pre-service educators is affected when they are required to evaluate the veracity (i.e., conforming to fact) of neuro-statements. Differentiating between -myth and -fact is a necessary skill upon entering the classroom to reduce the perpetuation of misinformation. No studies to the authors' knowledge employ a mouse-tracking paradigm to investigate neuro-statement endorsement; however, such method is useful because it allows cognitive scientists to determine whether uncertainty (measured by x-flips; i.e., the frequency of mouse-cursor reversals crossing the midline of the x-axis indicating decision-reversal prevalence) is occurring during the decision-making process. If individuals repeatedly move the cursor back and forth over the x-axis, it would suggest difficulty deciding between the forced-choice options (See Fig. 1). Typical measures of implicit processing (i.e., reaction time;

Shtulman & Valcarcel, 2012) do not provide data on how cognition changes during response selection (Freeman & Ambady, 2009).

This study investigates whether or not pre-service educators explicitly endorse neuromyths (Research Question 1 - RQ1) and whether implicit beliefs about neuromyths and -facts create interference during the process of making veridicality judgments (i.e., an assertion of truth) (Research Question 2 - RQ2). RQ2 contributes to the literature, as it employs a novel method to investigate both implicit and explicit endorsement of neuromyths as well as the level of uncertainty associated with veridicality judgements. The working hypotheses tested in this paper are as follows: Pre-service educators exhibit some level of neuromyth endorsement (RQ1) and demonstrate uncertainty (i.e., interference between new and prior knowledge) about veridicality of neuro-statements (RQ2). From a conceptual-change perspective, two possibilities exist regarding what happens to existing knowledge when new information enters the system (1) dramatic restructuring of prior knowledge or (2) supplementation of prior knowledge. If dramatic restructuring occurs in pre-service educators, action dynamics should indicate little, to no, evidence of uncertainty (x-flips) between new and prior knowledge in the decision-making process. Alternatively, if knowledge change is supplemental, action dynamics should reveal evidence of uncertainty during the decision-making process, contingent on newly learned knowledge not aligning with prior knowledge. Therefore, the strength of belief should be related to the amount of uncertainty (RQ2) when making veridicality judgments about neuro-statements due to the competition experienced between new and prior knowledge.

Method

Participants

Participants included 40 undergraduate pre-service educators from a Midwestern University (women = 33, men = 6, non-binary = 1; age range = 18-30 yrs). The majority of the pre-service educators (77%) majored in either Early Childhood Education or Adolescent and Young Adult Education. Approximately 23% of the participants are majoring in Middle Childhood Education, Special Education, Art Education, or other. The majority of participants (40%) reported *no* subject-matter concentration (e.g., specialized coursework in science or math pedagogy) The breakdown for participants who did report a subject-matter concentration is as follows: Language Arts (10%), Art, American Sign Language, Math, Social Studies and Special Education (each accounting for 7.5%), and Science falling below 1%. All participants reported enrollment in at least one educational psychology course that included explicit instruction to dispel neuromyths prior to the start of the current experiment.

Equipment & Stimuli

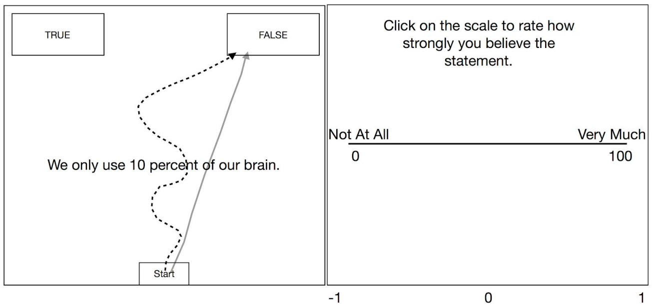
Data was collected on a Dell Windows 10 desktop computer with a 22-inch widescreen (16:9) monitor using the MouseTracker program (Freeman & Ambady, 2010) and a wired, optical computer mouse. Stimuli included a total of 20 neuromyths (e.g., *We only use 10% of our brain.)* and 15 neurofacts (e.g., *We use our brains 24 hrs a day.*) about the human brain, consistent with stimuli used by Macdonald et al., (2017). Three additional statements (one neurofact and two neuromyths) were added to the survey by MacDonald et al. (2017) to include current misconceptions in cognitive science (e.g., *Forgetting is good for memory.*).

Design & Procedure

To evaluate pre-service educators' ability to determine the veridicality of neuro-statements, a computer mouse-tracking paradigm, implementing a two-factor statement type (neuromyth; neurofact), within-subjects design was used. In the current study, we evaluated uncertainty as it relates to veridicality judgement, as this measure may reflect the strength of pre-service educators' neuromyth and -fact endorsement. This measure also provides data regarding the early implicit decision-making process during perception and action.

We seek to answer the research questions using the MouseTracker program to display common neuromyths and -facts randomly to participants. Each experimental trial (n = 35) presented an orthographic, visual presentation of the statement paired with two alternative forced-choice response options, counterbalanced across trials (see Fig 1 - left panel).

Participants were instructed to begin moving their mouse as soon as the statement appeared on the computer screen. Should they move too slowly, a warning prompt appeared after a response was made, asking participants to speed up their response. Following each response selection, an analog linear scale was presented on the participants' computer screen, requiring them to indicate how strongly they believed the statement just assessed for veridicality (see Fig. 1 - right panel).


We only use 10 percent of our brain.

Click on the scale to rate how strongly you believe the statement.

Figure 1: Shows a sample screen of the MouseTracker program, with a simulated mouse-cursor trajectory reflecting uncertainty (left panel; x-flips: uncertain - dotted

curved line; certain - solid straight line) and a sample screen displaying the analog linear scale in which 0 = no belief and 100 = very much believe (right panel). Along the bottom of the figure (not displayed to participants) is the scale at which the x-coordinate measure is reported in reference to the rating scale.

Measures and Analytic Approach

We collected four measures: reaction time, proportion true, x-flips, and belief-strength ratings. Reaction time was collected as a manipulation check and was not included in the main analysis. Details for each measure are listed below, with Table 1 displaying descriptives for each measure.

Reaction Time is a typical measure of interference in many misconception paradigms (e.g., Shtulman & Valcarcel, 2012; Potvin, Masson, Lafortune, & Cyr, 2015). This literature suggests the longer the reaction time, the more interference occurring between new and prior knowledge, as a result of more time and effort needed to process competing information.

Proportion True Participants chose between the response options TRUE (coded as 1) and FALSE (coded as 0) on each experimental trial. The dichotomous response choice provides a metric of explicit decision making about the statements' assumed veridicality (see Fig 1 - left panel).

X-flips refer to the frequency of reversals crossing the midline of the x-axis as the optical mouse cursor travels upward along the y-axis toward the explicit and final response option. X-flips are associated with measures of uncertainty or indecision (Roche, Peters, & Dale, 2015), as they indicate the frequency of decision reversals during the real-time, decision-making and selection process, typically resulting in a zig-zag pattern (see Fig 1 - simulated mouse-cursor trajectory).

Belief-Strength Rating refers to how strongly participants believed each neuro-statement. Participants recognizing a statement as a neuromyth and as completely false should exhibit a belief rating close to -.85 and neurofact as completely true should reflect a belief rating close to .85 (see Fig. 1 - right panel, under the x-axis of the computer screen display). Any response close to 0 should reflect moderate strength of belief in the neuromyth or neurofact. As shown in Table 1, regardless of participants' explicit veridicality judgment, each statement carried some level of belief. Means and standard deviations from Table 1 indicate the majority of participants did not have strong disbelief or strong belief in any of the statements, as most belief ratings were hovering just past 0 on the analog linear scale.

Analytic Approach included generalized logit (RQ1: binary outcome variable) and poisson (RQ2: count outcome variable) mixed random effects models, with subject and item set as random intercepts. Manipulation check models implemented linear mixed random effects models. Maximal random effect structure was implemented permitting model convergence (Barr, Levy, Scheepers, & Tily, 2013), implementing a backwards leave-one-out approach until model convergence was met. All analyses are posted on the open science framework (https://osf.io/p2h4g/). Data files will be posted pending IRB approval.

Table 1: Mean and standard deviation (SD) for reaction time, proportion of true response option selection [p(True)], and belief-strength rating for trials selected as True [Belief-Strength(T)] or False [Belief-Strength(F)]. X-flips are reported as frequency counts, means, and standard deviations [frequency: x-flips(f) and mean: x-flips(m)].

Measure	*Neuromyth*	*Neurofact*
RT	5758.62(2872.30)	5442.81(3134.80)
p(True)	0.57(.49)	0.81(.40)
x-flips (f)	5465	4387
x-flips (m)	7.06(3.61)	7.31(3.67)
Belief-Strength (T)	0.31(.31)	0.35(.32)
Belief-Strength (F)	-0.04(.54)	-0.03(.48)

Results

The present study poses two research questions to determine whether pre-service educators endorsed neuromyths (RQ1) and whether uncertainty in the decision-making process was affected by neuro-statement type and/or strength of belief about the statement's veridicality (RQ2). As a manipulation check, we assessed differences in reaction time, as most paradigms use this measure. The results (linear mixed random effects model) were consistent with the notion that interference exists when assessing the veridicality of misconceptions, as evidenced by a significant interaction between the response option selected and statement type ($\beta = -1303.73$, $SE = 390.87$, $t = -3.34$, $p < .001$). Specifically, longer reaction times were associated with assessment of neuromyths as True and neurofacts as False.

Research Question 1

Proportion True To answer RQ1, a logit mixed random effects model was used to evaluate correctness (1 = True; 0 = False) by statement type (neuromyth; neurofact). Pre-service educators were nearly 6 times (odds ratio = 5.95) more likely to correctly identify the veridicality of the neurofacts relative to neuromyths -- $\beta = 1.78$, $SE = .18$, $z = 10.15$, $p < .001$; marginal $R^2 = .18$, conditional $R^2 = .24$. These results are consistent with Macdonald et al. (2017), indicating our pre-service educator sample also has misconceptions about neuromyths (see Fig 2).

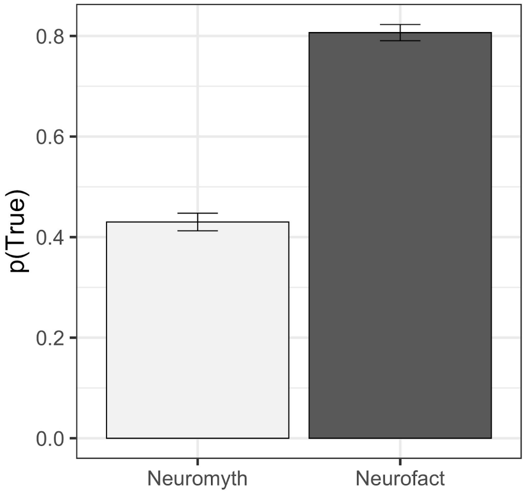


Figure 2: Means and standard error bars associated with the proportion of true response option selections as a function of neuro-statement type (neuromyth; neurofact).

Belief Rating Though it is clear from the present findings that pre-service educators tend to exhibit some endorsement of neuromyths, we also wanted to determine the strength of their neuromyth endorsement. A linear mixed random effects model was used to evaluate belief ratings as a function of neuro-statement type (neuromyth; neurofact) and response option selected (True; False). Results indicate a significant main effect of response option selected, such that the pre-service educators were significantly more likely to indicate stronger belief of statements they selected as True -- $\beta = .32$, $SE = .06$, $t = 5.44$, $p < .001$; marginal $R^2 = .15$, conditional $R^2 = .53$. However, the main effect of neuro-statement type ($p = .80$), and its interaction with the response selection ($p = .13$) was not significant.

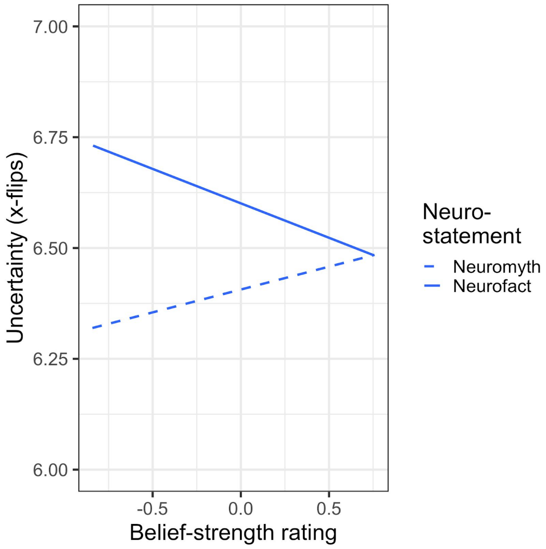


Figure 3: Relationship between x-flips and belief ratings as a function of neuro-statement type.

Research Question 2

A poisson mixed random effects model evaluated x-flips by statement type (neuromyth; neurofact) by response option selection (True; False) by belief rating (marginal $R^2 = .01$; conditional $R^2 = .30$). Results indicated a significant neuro-statement type by rating interaction ($\beta = -.17$, $SE = .09$, $z = -2.01$, $p = .04$; see Fig 3) and a response option selection by rating interaction ($\beta = .21$, $SE = .08$, $z = 2.62$, $p = .009$; see Fig 4). No other main effects or interactions were significant. As seen in Fig. 4, pre-service educators tended to exhibit more uncertainty with neurofacts when they did *not* believe the statements to be true relative to neuromyths. Additionally, pre-service educators had a tendency to exhibit more uncertainty when they more strongly believed items they selected as TRUE (see Fig 4).

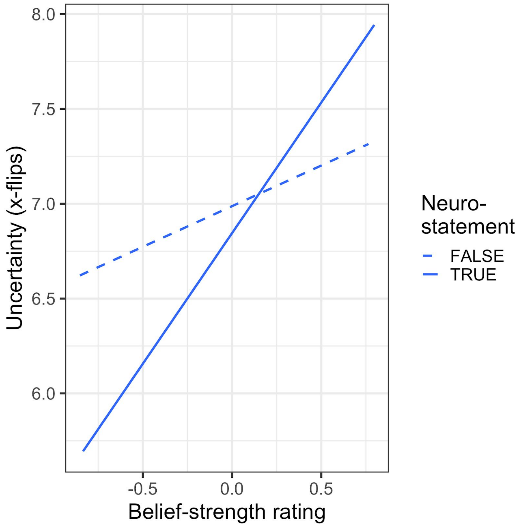


Figure 4: Relationship between x-flips and belief ratings as a function of response option selection (True; False).

Discussion

Data from the present study indicate pre-service educators endorsed neuromyths (replicating findings from Macdonald et al. 2017 with a pre-service population) -- even after having experienced explicit training in prior undergraduate coursework on what is and is not factual about the mind, brain, and learning. The continued endorsement of neuromyths suggests participants may have experienced interference between the new knowledge gleaned from their coursework dispelling previously held neuromyths and prior, albeit incorrect, knowledge. This finding is consistent with prior work suggesting prior knowledge is supplemented rather than dramatically restructured or overwritten when new information enters the system (Shtulman & Valcarcel, 2012; Vosniadou, 2012). Thus, the internal competition between new and prior knowledge may explain participants' uncertainty about both neurofacts and -myths.

Further, in the current study, pre-service educators exhibited the most uncertainty (i.e., more x-flips; implicit; Roche, Peters, & Dale, 2015) when they did *not* endorse a neurofact (i.e., selected false; explicit). More interesting, the levels of uncertainty seemed to converge (Fig. 3) such that uncertainty increased when participants believed neuromyths and decreased when they believed neurofacts. Work is underway to investigate why this convergence occurs. This uncertainty may undermine evidence-based decision making about instruction and classroom management (Simmonds, 2014), as educators may experience interference from previously held misconceptions, regardless of explicit training suggesting otherwise (Ansari & Coch, 2006; Dubinsky, Roehrig, & Varma, 2013; Im, Cho, Dubinsky, & Varma, 2018). Taken together, these results show that pre-service educators have difficulty distinguishing neurofacts from neuromyths.

Though the current findings provide valuable insights into the underlying cognitive processes associated with knowledge interference, limitations exist. We cannot be certain the explicit instruction from prior coursework successfully dispelled neuromyths nor can we determine whether individuals made an attempt to update their knowledge. Nevertheless, this study reveals, through action dynamics, the decision-making process that affects explicit judgments, providing a necessary first step in evaluating educator cognition in this context. Because these judgements are not always based in science, educators' explicit and implicit beliefs may differ substantially from scientific evidence, leading to inappropriate use of time or resources within the classroom (Pashler et al., 2008; Simmonds, 2014). An important next step, then, is to investigate possible interventions. Future studies should examine whether it is possible to elicit explicit and/or implicit cognitive change. Much of the work in this domain has investigated the prevalence of neuromyths in different groups (e.g., biology teachers, Grospietch & Mayer, 2019; primary/secondary teachers in Turkey; Karakus, Howard-Jones, & Jay, 2015; general public, Macdonald et al., 2012) but little work has investigated ways to correct these beliefs.

Because misconceptions about the brain and learning are a pervasive issue in education, future studies are planned to consider and control for these limitations. Work is also underway to develop possible interventions to mitigate the effect of these misconceptions.

Conclusion

The widespread adoption of neuromyths (Dekker et al., 2012; Howard-Jones, 2014; Macdonald et al., 2017), a subset of misconceptions, is one example of the general population's inability to distinguish information supported by evidence from supposition and hyperbole. Once learned, misconceptions are difficult, if not impossible, to overwrite -- even when presented with new, correct information (Goldberg & Thompson-Schill, 2009; Gregg et al., 2001). Rather, incorrect prior knowledge, (i.e., misconceptions) and new evidence coexist, creating the potential for interference when making decisions about the veridicality of statements (Shtulman & Valcarcel, 2012). Prior work suggests implicit processing can influence explicit decisions via increased uncertainty during the decision-making process (Masson et al., 2014; Shtulman & Valcarcel, 2012). The current study adds to the literature by investigating both implicit and explicit processes underlying a subset of misconceptions using a novel method. Investigation of this particular subset of misconceptions is of value because it has the potential to be multiplicative in nature, as students taught via misinformed science may continue to perpetuate misinformed science as they age.

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