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Does Connecting the Processes and Products of Science Facilitate Learning? A Schema-Based Approach

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Abstract

Understanding both the processes and products of science are core components of science literacy, but do these types of knowledge interact during learning? We propose that *Nature of Science (NoS)* understanding can act as a schema to facilitate comprehension of science content. Across two experiments, we tested whether NoS lessons about theory change improve students' comprehension of psychology lessons which are centered around theory development. In Experiment 1, undergraduates who watched a NoS lesson showed improved NoS understanding, but this understanding did not lead to better comprehension of a matched psychology lesson compared to control. In Experiment 2, three NoS lessons were experimentally integrated into a college psychology course, preceding content lessons involving theory change. While this intervention did not improve learning, we found several relationships between science beliefs and academic performance. This work contributes to our limited understanding of how these distinct components of science knowledge interact during learning.

Keywords: nature of science; science learning; schema theory; cognitive psychology

Scientific and pseudoscientific information is pervasive in everyday life. Reasoning accurately about such information not only requires science content knowledge, but also an appreciation of how knowledge in science is constructed and verified. Both of these distinct understandings of science – the *processes* and *products* of science – are vital goals of science education (Lederman, 2013a). Effective instructional design not only requires understanding how students best learn these components of science in isolation, but also whether they interact with each other in the learning process. Does understanding the products of science aid learning the processes of science? Does understanding the processes of science aid learning the products of science? If so, how?

The Processes of Science as the Nature of Science *Nature of Science (NoS)* includes an understanding of the processes and practices of science (Weisberg et al., 2021), and the values and beliefs inherent to scientific knowledge and its development (Lederman, 2013a). A related term, epistemic beliefs, refers to individuals' beliefs about the nature of knowledge (Bromme et al., 2010), often applied to science. National education standards specify that target understandings of the nature of science include that science is (1) subject to change, (2) based on empirical evidence, (3) a human endeavor, and (4) a way of knowing about the natural world (Council et al., 2013), though there are nuances

among prominent conceptualizations (Greene et al., 2018; Hofer, 2000).

Connecting the Processes and Products of Science First, does understanding the products of science – i.e., content knowledge about the natural world — facilitate learning the nature of science? Evidence suggests so. For example, scholars have highlighted that learning science content, including historical errors in science (Allchin, 2012), can develop students' understanding of how science works (Lederman & Lederman, 2019). These findings are consistent with theories of knowledge acquisition which posit that abstract concepts are best reinforced by domain-specific examples (Nathan, 2012). According to this view, knowing specific examples of theories changing in science is needed to help students develop an abstract understanding of theory development in the nature of science. Moreover, there is consensus that explicit approaches of teaching the NoS are more effective than implicit approaches (e.g., explicitly extracting NoS themes from science examples vs. assuming students will extract the themes on their own) (Lederman, 2013b). Accordingly, scholars have called for a better integration of NoS concepts in science domain classrooms (Lederman & Lederman, 2019).

But what about the other direction: does understanding the nature of science facilitate learning science content? Evidence is less clear. While some evidence suggests that NoS and epistemic beliefs are related to educational performance (i.e., measures ranging from GPA to individual content question performance; Greene et al., 2018; Michel and Neumann, 2016), most of it is correlational in nature. There is some interventional data, but most of the interventions use a combination of techniques (e.g., NoS instruction plus metacognitive scaffolding; Cartiff et al., 2021), making it difficult to tease apart which components were responsible for the improvement in academic performance. While the design of these studies assume NoS understanding supports educational achievement – in particular learning science content – the mechanism of such a relationship remains empirically unsubstantiated. Thus, there is a need for well-controlled experimental data to better test this assumption.

A Novel Causal Mechanism To undergo such investigations, a plausible theoretical mechanism(s) must first be identified: how exactly would NoS understanding aid learning science content? There are currently very few formal the-

ories. Some scholars argue the relationship could exist due to the mediating effect of self-regulated learning (Muis & Franco, 2009). For example, Bromme et al., 2010 explain that epistemic beliefs can inform standards for learning (i.e., internal perceptions of what it means to have ‘learned’ something), which subsequently affects the engagement with material (e.g., learning strategies), and the level of engagement ultimately affects learning. While this mechanism is plausible, we propose that a more direct cognitive relationship may exist between these two types of knowledge. In fact, Driver et al. (1996) suggest that NoS understanding may support science concept acquisition by fostering students’ abilities to make connections between concepts. Expanding this theory, we propose that NoS may act as a schema to facilitate understanding novel concepts in science. Notably, this theory predicts that NoS understanding directly affects concept comprehension and knowledge acquisition (i.e., learning), independent of mediating behaviors such as learning strategies. On the other hand, these two types of science knowledge may be too conceptually distinct in learners’ minds to observe such schema-learning effects.

Schema Theory A schema is an abstract knowledge structure that guides an individual’s expectations, attention, and inferences in novel situations (Rumelhart, 1980). Schema theory played a crucial role in the cognitive revolution (Iran-Nejad & Winsler, 2000), and remains a prevailing approach in understanding comprehension (Anderson, 2018). Schemas can either facilitate or impede learning: when a learner has an accurate and well-organized schema, it provides a cognitive framework onto which the new information can be mapped effectively, a process known as assimilation (Piaget, 1978). However, if a learner possesses an inaccurate or irrelevant schema for the new information, this assimilation process will result in the information not being comprehended accurately or not even comprehended at all (Graesser & Nakamura, 1982). On the other hand, when a learner possesses an ill-fitting schema but recognizes its discrepancy with new information, the learner must accommodate this existing knowledge structure to match the new information (Piaget, 1978). Though this accommodation process can ultimately lead to an accurate representation of the information at hand, it is a demanding process requiring cognitive load, which can indirectly hinder learning the content (Sweller & Chandler, 1991). Those who already hold the accurate schema for the target content do not have these additional constraints on cognitive load and are better equipped to learn the information at hand.

In regards to the current investigation, this theory predicts that if an individual learner holds a schema about the nature of science that matches the structure of the novel science content, they will learn that content better than a learner who holds an inaccurate or incomplete schema. For example, consider a lesson in science that describes the relationship between previous and current theories of a phenomenon. If a learner does not understand that science is susceptible

to change and that theories in science often build on each other, they may not have a pre-existing structure to help them integrate the outdated and the current theory into their conceptual understanding of that concept, thus requiring them to either shape the new information to their existing structures (i.e., learning incorrectly), or adapt their schema of science to fit the new information (i.e., using cognitive load that would otherwise be available for learning).

Schema Induction Testing whether and how understanding the processes of science can facilitate learning the products of science requires careful experimental design, and previous research on schema-induction provides guidance. In a seminal study by Gick and Holyoak (1980), participants were trained on a solution to a source problem that was abstractly analogous to the solution of a target problem. That is, the topics of the source problem and the target problem were different, but the solutions were guided by the same underlying structure. They found that those who received the source problem solved the target problem at higher rates than those who did not, and the authors indicate that these results provide evidence for “problem-schema” induction. Likewise, Quilici and Mayer (1996) found that novice statistics learners who were provided worked examples of three types of statistics problems (t-test, chi-squared test, and correlation) were better able to categorize subsequent problems correctly than novices who were not provided examples. In particular, participants who received examples were more likely to group the problems based on their structural similarity rather than surface similarity, indicating that the example-training helped the participants recognize the underlying structure of the target problems.

Based on these findings, we predict that if a NoS example lesson helps learners identify the underlying structure in the target science concept, and identifying that underlying structure is crucial for understanding that concept, then learning will be supported by our intervention.

Current Investigation

The current study investigated whether NoS can act as a schema to facilitate learning science content in two controlled experiments. We chose science lessons that were scaffolded by one of the most central nature of science themes: theory change. In order to properly investigate whether NoS schemas directly affect science content comprehension independent of elective behaviors, we evaluated comprehension directly after the initial interaction with the novel material.

Does receiving a NoS lesson aid learning a science content lesson when the two lessons are structurally matched? Across the two experiments, we predicted that (1) participants in the experimental condition would perform better on the NoS comprehension check compared to control (manipulation check), (2) participants in the experimental condition would perform better on the content comprehension test compared to control (primary hypothesis), and (3) participants in the experimental condition would report more sophisticated

NoS beliefs compared to control (secondary hypothesis).

Experiment 1

Method

Participants 211 participants were recruited from a psychology subject pool at a large public university in the western United States ($M_{age} = 20.1$, $SD_{age} = 1.7$; 153 female, 51 male, 7 other gender).

Lessons The target science content lesson was on theories of selective attention: it describes two initial competing hypotheses (early selective and late selection) followed by a perspective shift and a new theory (load theory of attention), which explained previously conflicting data. In order to test our intervention in comparison to how this lesson is typically taught, we used material from the leading textbook in the field (Goldstein, 2007) to create the slides and script of the video lesson. The NoS lesson was designed to facilitate a schema that structurally matched the target content lesson; it began by describing the scientific process and explicitly emphasizing the cyclic and tentative nature of science, then described how paradigm shifts occur and finally, illustrated two examples of paradigm shifts from the history of science (i.e., germ theory and nature vs. nurture).

Tests There were four short-answer questions about selective attention. A retention question asked participants to recall the lesson content, and three transfer questions asked about the relationships between theories, as this is the central conceptual understanding of the lesson (e.g., “Please explain how load theory accounts for both the early and late selection patterns of selective attention”). There were five short-answer comprehension questions about the NoS lesson (two retention and three transfer; e.g., “to the best of your ability, please describe what a paradigm shift is in the context of science”).

Questionnaires We measured NoS beliefs through two standardized epistemic belief questionnaires, each referencing different domain-specificities because consensus indicates that epistemic beliefs are domain-specific (Greene et al., 2016; Merk et al., 2018; Muis et al., 2006), though it’s not clear exactly what level of specificity is most accurate. First, we measured participants’ beliefs in reference to the field of selective attention through Hofer (2000)’s *Discipline-Focused Epistemological Beliefs Questionnaire (DEBQ)*. This measure captures the following epistemic belief dimensions: Certainty/Simplicity (e.g., “Truth is unchanging in this subject”), Personal Justification (e.g., “Correct answers in this field are more of a matter of opinion than fact”), Source Authority (e.g., “If you read something in a textbook for selective attention you can be sure it’s true”), and Attainment of Truth (e.g., “If scholars try hard enough, they can find the answers to almost anything”). Second, we measured participants’ beliefs in reference to science in general through Conley et al. (2004)’s *Epistemological Beliefs in Science Questionnaire (EBSQ)*. This measure captures the

following dimensions: Development (e.g., “New discoveries can change what scientists think is true”), Certainty (e.g., “All questions in science have one right answer”), Source (e.g., “If you read something in a science book, you can be sure it’s true”), and Justification (e.g., “In science, there can be more than one way for scientists to test their ideas”). For both questionnaires, participants were prompted to indicate their level of agreement with each statement on a 5-point Likert scale from strongly disagree to strongly agree.

Procedure Participants completed the experiment in-person on laboratory computers. Participants were randomly assigned to one of two conditions: control ($n = 106$) and NoS ($n = 105$). Participants in the NoS condition first watched the NoS lesson, and then the selective attention lesson. Participants in the control condition simply watched the selective attention lesson, again to test our manipulation against the standard teaching method of the lesson. There were no other differences between conditions. Directly following the selective attention lesson, participants answered the selective attention comprehension questions. Then, the participants answered the NoS comprehension questions. We placed the selective attention questions before the NoS questions to ensure there were no influences of NoS question-prompting on our measurement of selective attention comprehension. Following the tests, participants completed the two NoS beliefs questionnaires and finally, answered questions regarding their demographics and prior knowledge. The experiment took participants approximately one hour to complete.

Results

There were no differences between the two groups on prior knowledge. An independent samples t-test revealed a large effect of condition on overall NoS comprehension, $t(209) = 6.05$, $p < .001$, $d = 0.83$. Our manipulation was effective: participants in the NoS condition demonstrated greater nature of science understanding than control. Additional independent samples t-tests revealed no significant difference between conditions ($\alpha = .05$) for selective attention comprehension (retention and transfer), or any of the eight NoS belief dimensions (i.e., predictions 2 and 3 were not supported). Notably, we did not find any effects on development, the most heavily emphasized NoS dimension in our intervention, though the high means observed suggest a ceiling effect on this measure ($M = 4.71$; $SD = .36$; *maximum score* = 5.0).

We combined conditions to conduct Spearman’s rank order correlation tests ($\alpha = .05$) evaluating the relationship between NoS beliefs and nature of science and selective attention comprehension. The Personal Justification dimension from DEBQ was negatively correlated with all four comprehension tests: NoS Retention ($\rho = -.21$), NoS Transfer ($\rho = -.29$), Selective Attention Retention ($\rho = -.22$), and Selective Attention Transfer ($\rho = -.23$). The higher the score on this dimension, the more naive the belief, thus the negative directionality is appropriate. The Certainty/Simplicity dimension from DEBQ and the Certainty dimension from EBSQ were

both negatively correlated with NoS Transfer ($\rho = -.28$ and $\rho = -.17$, respectively), though not with any other comprehension measures. Again, the higher the score on this dimension, the more naive the belief, and thus the negative directionality is appropriate. No other correlations between the questionnaire subscales and learning outcomes were significant. These results suggest that NoS beliefs, particularly personal justification in selective attention and certainty of knowledge, are related to science comprehension, though the mechanism remains unclear due to the correlational nature of these findings.

Experiment 2

In Experiment 1 we successfully manipulated NoS knowledge, but this understanding did not impact learning relevant science content or NoS beliefs. It is possible these two forms of science knowledge are too conceptually distinct in learners' mind, yielding an incapacity to connect the structural similarities we targeted. On the other hand, we recognize 1) the limited efficacy of one-shot interventions, and 2) that there may be substantial differences in individuals' motivation to learn in research studies compared to authentic classrooms. Because the majority of the previous research on the relationship evaluates authentic academic performance measures, we sought to test our hypothesis in a real classroom with a more long-term intervention.

Method

Participants and Procedure In an online introductory cognitive psychology course at the same large public university in the spring of 2024, 309 undergraduate students were randomly assigned to either the control ($n = 156$) or NoS condition ($n = 153$). Those in the control received no additional instruction, whereas those in the NoS condition received three NoS lessons integrated throughout the course embedded in the video lectures placed right before the target content lessons. Each week after the lectures, students answered short answer comprehension questions on the content. At the beginning and ending of the quarter, students filled out a survey regarding their beliefs for extra credit; we only report findings from the end of quarter beliefs because this matches Experiment 1 analyses, it is our only full dataset (i.e., includes data about auxiliary science beliefs), and because conditions were randomly assigned, allowing for causal interpretations of data ($n = 199$ completed the end of the quarter questionnaire; $M_{age} = 19.76$, $SD_{age} = 1.7$; 150 female, 44 male, 6 other gender).

Lessons Three content lessons in which theories change in cognitive psychology were targeted for this intervention: (1) theories of selective attention, (2) the transition from short-term memory to working memory paradigms, and (3) updates to theories of the reliability of eyewitness memory. For the NoS group, each target lesson was directly preceded by a structurally-matched NoS lesson: the first focused the same theory change content as Experiment 1, the second on how

theories in science build on each other, with a historical example (i.e., Mendelian genetics expanding Darwin's theory of natural selection), and the third on how theories come to be accepted in the scientific community, emphasizing the need for substantial empirical evidence and the social processes of discussion, debate, and peer-review. The last two lessons also highlighted why scientific knowledge is still reliable, despite its tentative nature, aiming to safeguard students from developing 'nihilistic' views of science.

Tests Embedded in the course, after each weekly lecture video, there was a short-answer quiz. For the three weeks with the target lectures, there were two short answer questions about the target content and one short answer question about the NoS lesson. All questions were written to make sense to students in both conditions. These questions are designed to be the target questions answered right after students interact with the novel content, though this is not as tightly controlled as Experiment 1 in the laboratory. There were also two multiple-choice questions per lesson on exams. All content target questions asked about the relationship between the theories.

Questionnaires In the beginning and ending of the quarter survey, students answered several questions regarding their science beliefs. First, students completed the entire EBSQ referencing science and the Personal Justification dimension from DEBQ referencing psychology. We did not measure the other three dimensions from the DEBQ because there is notable overlap between it and the EBSQ and we wanted to evaluate more unique dimensions in the second experiment. Thus, we also measured students' beliefs about the role of social negotiation in science through a dimension in Tsai and Liu (2005)'s *Epistemological Views toward Science (EVS)* questionnaire. The Social Negotiation dimension refers to the view that the development and validity of science relies on communications and negotiations among scientists, opposed to individual efforts and exploration.

Furthermore, using Weisberg et al. (2021)'s *Epistemological Thinking Styles (ETS)* measure, we evaluated students' beliefs about science regarding an applied scenario about the cause of leg deformities in endangered frogs. Participants read about the debate and then were prompted to indicate their agreement with various responses regarding the issue, each of which corresponded to one of three epistemological thinking styles: Absolutism (the view that knowledge in science is objectively true and can be easily accessed through observation), Multiplism (the view that knowledge in science is subjective because it is generated by humans and thus is just as valid as any other view), and Evaluativism (the view that though knowledge in science is inherently uncertain, it is reliable through continuous evaluation and updating in light of new evidence). For example, participants were prompted by the question: "what should scientific knowledge about the deformed frogs be based on?", and then were asked to rate their agreement with the response: "mainly on personal points of

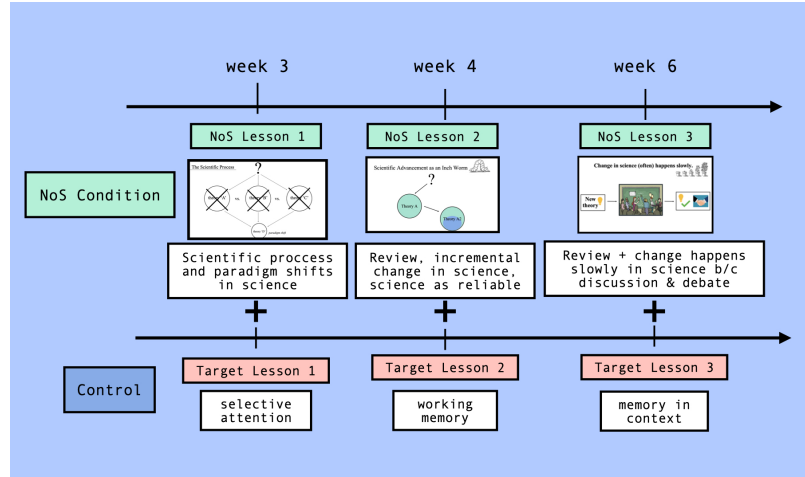


Figure 1: Experiment 2 Design.

view” (referring to multiplism). Evalutivism is considered the most sophisticated NoS belief in this framework. Therefore, there were nine total epistemic/nature of science belief dimensions evaluated in this experiment.

Finally, we measured (1) trust in science through the *Trust in Science and Scientist Inventory* (Nadelson et al., 2014), and (2) evolution acceptance through the *MATE 2.0* (Barnes et al., 2022) to measure auxiliary beliefs related to science literacy for exploratory analyses. Following how each measure was standardized, participants rated their level of agreement with the statements on either a 5-point or 7-point Likert scale from strongly disagree to strongly agree.

Results

We conducted independent samples *t*-tests ($\alpha = .05$) to evaluate whether conditions affected end of quarter NoS beliefs ($n = 199$). We found a small effect of condition on the Multiplism dimension, $t(197) = 2.27$, $p = .023$, $d = 0.32$, indicating that those who received the NoS intervention had lower beliefs of multiplism in science, a desirable improvement. We did not find any other significant effect of condition on NoS beliefs. Participants in this experiment were also high on the Development dimension, again suggestive of a ceiling effect ($M_{age} = 4.57$; $SD_{age} = .63$; maximum score = 5.0). One target exam question was discarded because performance was below chance. Independent samples *t*-tests ($n = 309$) revealed no overall effect of condition on target exams, multi-

ple choice questions, overall exam scores, or total number of points received throughout the course (i.e., final grade). Short answer scoring is ongoing.

Finally, we combined conditions to conduct Spearman’s rank order correlation tests ($\alpha = .05$) evaluating the relationship between science beliefs and academic performance ($n = 199$). We did not find any relationships between EBSQ dimensions and academic performance. We found small-moderate correlations between the Social Negotiation dimension and all three exam scores (exam 1: $\rho = .32$; exam 2: $\rho = .22$; exam 3: $\rho = .22$), as well as final grades ($\rho = .28$). The same was true for the Personal Justification in psychology dimension (exam 1: $\rho = -.19$; exam 2: $\rho = -.16$; exam 3: $\rho = -.14$; final grade: $\rho = -.24$). Negative directionality is again appropriate for this relationship. For auxiliary science beliefs, we found small-moderate correlations between trust in science and exam 1 score, exam 3 score, and final grade (exam 1: $\rho = .26$; exam 3: $\rho = .14$; final grade: $\rho = .19$), as well as evolution acceptance (exam 1: $\rho = .35$; exam 3: $\rho = .29$; final grade: $\rho = .27$). It is not evident to us why we did not find a relationship between exam 2 and these auxiliary science beliefs compared to the other achievement measures. No other correlations between the questionnaire dimensions and learning outcomes were significant.

Table 1: Significant Correlations Between Science Beliefs and Academic Performance in Experiment 2.

	Social Negotiation	Personal Justification	Trust in Science	Evolution Acceptance
Exam 1	$\rho = .32$	$\rho = -.19$	$\rho = .26$	$\rho = .35$
Exam 2	$\rho = .22$	$\rho = -.16$	NS	NS
Exam 3	$\rho = .22$	$\rho = -.14$	$\rho = .14$	$\rho = .29$
Final Grade	$\rho = .28$	$\rho = -.24$	$\rho = .19$	$\rho = .27$

Discussion

Our study is the first of its kind to experimentally test whether NoS understanding serves as a cognitive schema for learning science content, advancing both theoretical and practical frameworks for science education.

Empirical Contributions In Experiment 1, participants who received the NoS lesson performed better on the NoS questions regarding the scientific process and theory change. This understanding, however, did not support learning the target lesson. We also did not find any effect of condition on NoS beliefs, despite finding a difference between conditions on NoS comprehension; this could be because declarative beliefs about the nature of science are relatively stable. These results did not support our hypothesis that our NoS lesson intervention would improve learning novel science content. This could be because our intervention was too brief and/or different from typical learning environments.

In Experiment 2, we integrated our NoS intervention into an actual psychology classroom, and targeted three lessons involving theory-change instead of one. The intervention still did not affect learning on any of the analyzed dimensions, though short-answer scoring is still in progress. The intervention improved NoS beliefs on a single dimension: multiplism in science. It is unclear why this dimension was altered and other more targeted dimensions were not. This may be because the ETS measure captures judgments about an applied situation, making responses less stable and more malleable compared to the more explicit questionnaires (e.g., DEBQ). Across both experiments, we found several correlational relationships between science beliefs and achievement measures (e.g., personal justification in both experiments).

Theoretical and Practical Implications While our interventions did not affect science content learning, the efficacy of our intervention in fostering students' understanding of the nature of science is significant in itself. Science lessons that contain NoS themes should be leveraged to advance students' understanding of NoS, and our study provides a model for how this can be done in psychology. Moreover, we found several correlations between NoS beliefs and learning; these results are consistent with previous correlational data suggesting there is a relationship between how students think about the nature of science and academic achievement. However, as our current study indicates, more causal evidence is necessary to understand and apply this relationship. Finally, though schema theory has been used to explain a wide range of psychological phenomena – from visual perception to surprising stories (Axelrod, 1973; Iran-Nejad, 1986), it is yet to be tested in the context of nature of science instruction. This study tests schema theory in a novel and applied context by examining how two conceptually distinct forms of knowledge about the same topic may become co-activated and interact during the learning process, ultimately contributing to a richer understanding of the breadth and limitations of using schema theory to explain comprehension.

Limitations and Future Directions A noteworthy limitation of the current study is the difference in cognitive load demands between the two conditions; the experimental conditions add additional lesson(s) to the base (control) versions of the science content lessons. This choice was deliberate: we wanted to compare the intervention to a control condition aligned with typical instruction. Future investigations could add additional content to the control condition in order to match the conditions on this component, but such a change would reduce the ecological validity of the study.

In both experiments we did not observe the predicted benefit to learning from the NoS intervention. One possible explanation of this result is that participants in the experimental condition(s) did not adequately connect the NoS lesson to the content lesson. Scholarship on using schema theory to inform instruction suggests highlighting the connection between students' previous knowledge and the new content to aid assimilation processes (Meylani, 2024). Gick and Holyoak (1980) found that their schema-induction manipulation was most effective when participants were most prompted to make connections between the source and target problems. To adequately test the current research question and design, a future study should integrate explicit hints in the experimental conditions to connect the NoS lessons to the target content lessons, increasing the chances that participants recognize the common underlying structure between the two lessons posited to help them learn. Alternatively, our interventions may not have been effective because NoS understanding does not affect science content acquisition in the predicted manner; perhaps these are distinct, non-interacting categories of conceptual knowledge about science. Such an insight would likewise be important for instructional design in science; more causal investigation is necessary in either case.

Moreover, because our study populations seem to hold relatively sophisticated beliefs about the development nature of science and this may be influencing our results, future studies should consider testing the current research design on those who may hold less sophisticated NoS beliefs, such as non-college educated adults. Perhaps most crucially, our results suggest that future studies should target beliefs about the role of social negotiation, multiplism, and personal justification in science as they may be more malleable and influential on academic performance. Target lessons embodying these NoS themes could relate to other challenging topics such as the replication crisis and evolutionary explanations in psychology. The current NoS schema-induction design should also be applied to science domains outside of psychology for generalizability implications. Finally, future studies should consider using more applied and process-oriented measurements of NoS beliefs as they may be more sensitive and accurate measurements of how students think about science. Future investigations can provide further insight into whether and how students' understanding of the processes and products of science are related during learning, better informing effective instruction for science literacy.

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