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Investigating the Potential for Unanticipated Consequences of Teaching the Tentative Nature of Science

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A preliminary report

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If you are reading information supportive of climate science, you may well read that climate science is "settled science." If you are reading something from a climate science skeptic, you may well read that climate science is "just a theory." Given that the science education community strongly supports teaching the tentative nature of scientific knowledge, one might think that the skeptic has a legitimate argument. Experts will quickly object that such a deduction is quite wrong, and we agree. Nevertheless, we can't help but wonder to what extent teaching the tentative nature of scientific knowledge might undermine confidence in science, especially for those who have not grasped important epistemological nuances. Our paper reports the findings from an initial exploration of this possibility.

Research Background

Teaching the nature of science has become an important part of the science curriculum. While there is some disagreement as to exactly how the nature of science should be defined, most members of the science education research community agree that scientific knowledge by nature is tentative (e.g., McComas et al., 1998). A brief look at the literature indicates that there are many studies focusing on how well students and teachers have embraced this idea. There are also many practical papers on how to teach the tentative nature of science. Moreover, there are published NOS studies that have investigated the acceptance of controversial concepts such as evolution and climate change as a function of NOS knowledge (e.g., Carter & Wiles, 2014). There are NOS studies that have investigated "decision making on science and technology based issues" as a function of NOS knowledge (e.g., Bell & Lederman, 2003).

One also finds in the literature that certain theories in science are rejected by significant portions of the public, such as evolution and anthropogenic climate change. Often one can find these scientific ideas criticized as "just theories," with the implication that the ideas are speculative and should not be trusted as representing accurate knowledge.

> A central obstacle to accepting evolution, both among students and the general public, is the idea that evolution is "just a theory," where "theory" is understood in a pejorative sense as something conjectural or speculative. (Branch & Mead, 2008, p. 287)

In his book "Only a Theory," Kenneth Miller reports overhearing the following:

> This textbook contains material on evolution. Evolution is a theory, not a fact, regarding the origin of living things. This material should be approached with an open mind, studied carefully, and critically considered. (Miller, 2008, p. 2)

Such ideas of course indicate a misunderstanding of the scientific use of the concept of theory, and it's not surprising that the science community would rise in defense of science. Michela Massimi (2019) asserts that "Truth is neither absolute nor timeless. But the pursuit of truth remains at the heart of the scientific endeavor," adding that:

> The time for a defense of truth in science has come. It begins with a commitment to get things right... Climate science is true if what it says about CO_2 emissions (and their effects on climate change) corresponds to the way that things are in nature.

And we science educators are not found faultless:

> Perhaps a more pressing criticism of the way NOS is taught in schools is that it encourages rather too much doubt over scientific ideas. Many findings, after all, are well established and, indeed, taken as such by professional scientists who use them as shoulders to stand on. Not all science is

> tentative, and researchers should not be shy about saying so — both to those in schools and to those in charge of schools. (Nature, 2017, p. 149)

Giving serious attention to what concerns the editors at *Nature*, and realizing that it is a conceivable conclusion from the inherently tentative nature of science that evolution or climate change ideas are just that, tentative, we have wondered to what extent could the science education community's focus on the tentative nature of science actually be contributing to this misunderstanding of theory in science. The literature does not seem to contain studies that address any aspects of this concern though as a science education community we recognize the urgency for a public understanding of what scientific theory means, and what it means when we say that science is tentative. We thus have begun a series of studies investigating the relationship between a person's confidence in science and understanding of the tentative nature of science.

This paper reports on initial and replication exploratory studies involving about 500 preservice K-8 teacher education students at a large Midwest public university. Using a survey method that includes opportunities for student comments, the study initially tested two hypotheses:

> **Hypothesis:** Students have confidence in the veracity of scientific concepts even if they have doubts about some areas of science such as evolution or climate change.

> **Hypothesis:** Students *less* confident about the veracity of controversial concepts are likely to be *more* confident that scientific knowledge is tentative.

Bearing in mind the "just a theory" argument, we considered that students who oppose or who are uncomfortable with controversial science concepts may bolster their doubts by turning to the inherently tentative nature of science. On the other hand, students who are confident in science may have a more nuanced view of the tentative nature of science. We address these possibilities through the quantitative survey response means and correlations. In terms of the comments that students may make, we looked for evidence that students have reflected on the association of confidence in scientific ideas vis-à-vis the inherently tentative nature of science.

Methodology

<u>Study Design and Instrumentation</u>: We ran an initial study followed by a replication study more than a year later. The design for both studies asked students about their confidence in scientific concepts that are not considered controversial, scientific concepts that are, and their confidence in the nature of science as durable yet tentative. For non-controversial statements, we used a statement about Newton's First Law and one about heart/lung function. The researchers are experienced teachers of science, and we have not found these concepts to be controversial among students. Moreover, nothing in the literature suggests that they are. For controversial statements, we used human evolution and anthropogenic climate change, both of which are amply documented by the literature as controversial among the public. We wanted to avoid presenting items that appeared to test knowledge given that our interest is in confidence. Hence, we posed all items in the form of "according to the science community…"; and indeed, all of the statements are what might be called "settled science." The items were all cast in a Likert format followed by a space for comments. For example:

> Please read the following scientific statement. Using the scale below, indicate how confident you are that the scientific statement is true. In the space below, briefly explain your choice of confidence level.
>
> According to the science community, an object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.
>
> | 1 | 2 | 3 | 4 | 5 |
> |---|---|---|---|---|
> | Not at all confident | | | | Very confident |

Statements were content validated by the research group (which represents the science disciplines involved) and by several science professors and teachers. The statements used for the nature of science were reviewed by professors who do NOS research:

Initial Study Statements	
Non-controversial	According to the science community, an object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.
	According to the science community, the heart pumps blood to the lungs where oxygen is captured and then circulated throughout the body
Controversial	According to the science community, human activities are responsible for the recent rapid increase of Earth's average atmospheric and oceanic temperatures.
	According to the science community, all biological organisms, including humans, have evolved over time from common ancestors.
NOS: Durable/tentative	According to the science community, scientific knowledge is durable, but can change in light of new evidence or changes in perspective.

Replication Strategy: The literature in recent years contains a number of concerns that research too often is not substantiated through replication studies. Indeed, Makel and Plucker (2014, p. 304) "found that only 0.13% of education articles were replications." We sought to design our research in light of the concerns about replication, however, we quickly discovered that "there are many different meanings to [replication] and the relevant procedures, but hardly any systematic literature" (Schmidt, 2009, p. 90). Amongst other forms, there is both direct and conceptual replication. Conceptual replication varies "one or more dimensions (e.g., population, setting, research design) from a prior study" (Chhin, Taylor, and Wei, 2018; also see Schmidt, 2009). Coyne, Book, and Therrien (2016, p. 247) suggest that in a conceptual replication of a prior study, researchers might vary such dimensions as the participants, setting, or the outcome measures. Following Coyne et al. we adopted a conceptual replication strategy involving the variation of two outcome measures. We came to this decision based on findings of the initial study.

Sample and Data Collection: The sample for both studies was drawn from preservice, K-8 teacher education students enrolled in science content courses at a large Midwestern, public university. The courses were in the life sciences, physical sciences, and earth/space sciences, and specifically designed for K-8 teacher education. All courses include some NOS instruction. The initial study involved 303 students, with 202 students in the replication study. Data collection for both studies took place over the course of three weeks as follows:

Week 1	1st day	Non-controversial scientific statement: Newton's First Law (motion)
	2nd day	Controversial scientific statement: Anthropogenic climate change (warming)
Week 2	1st day	Controversial scientific statement: Biological evolution (evolution)
	2nd day	Non-controversial scientific statement: Heart/lung function (heart)
Week 3	1st day	Statement(s) on the Nature of Science (durable/tentative)(accurate & trustworthy) & demographic covariables: religiosity, science courses, politics, age, gender

In the first two weeks, subjects were asked to respond to both non-controversial and controversial statements about science. Data was collected in classes that met twice a week with one question asked per class meeting. In the third week, the subjects were asked the NOS question(s) as well as for demographic information. The spacing was intended to help minimize subjects from responding on the basis of their previous responses.

The initial study was conducted in 2015 and it returned the following means:

Confidence means 2015

	Year	N	Mean	SD
Motion	2015	297	4.48	.78
Warming (climate change)	2015	303	3.89	.99
Evolution	2015	298	4.19	1.01
Heart	2015	301	3.76	1.24
Science durable but can change	2015	296	4.42	.84

Conceptual Replication: Since we were collecting data from several science courses taken by our preservice, K-8 teacher education students, we ran the replication study in 2017 when the 2015 students would have completed their science courses and thus would not inadvertently end up in our replication study. We ran a conceptual replication in that we altered two outcome measures: the heart item and the nature of science item. We were surprised by the low mean for the heart item given that the item represented noncontroversial science. Written comments from the students suggested that some of them may have misunderstood the item. Hence, we wrote a new item deemed to have face equivalence, which is "the extent to which items appear to be eliciting the same underlying knowledge facet, opinion or perception" (Taber, 2018, p. 1288). We wrote the new item so that it addressed the same knowledge but using different words that we believed addressed misunderstandings implicit in student comments.

2015	According to the science community, the heart pumps blood to the lungs where oxygen is captured and then circulated throughout the body.
2017	According to the science community, circulating blood picks up oxygen as it passes through blood vessels in the lungs.

We also decided to rewrite the nature of science item again employing the criteria of face equivalence. The original item was written using common language in the literature of science education about the durable yet tentative nature of science. The 2015 mean for this item is high; however, we noted that none of the student comments had to do with durability, while several had to do with the tentative nature of science. It occurred to us that because the 2015 item contained two clauses, it was possible that readers attended more to the second clause than the first. This could happen simply as a matter of recency. It is easier to attend to things that are more recent; thus, unless the reader pays close attention to the entire statement, the reader could likely respond to the second part rather than to both parts.

Hence, we decided to split the clauses into two items:

2015	According to the science community, scientific knowledge is durable, but can change in light of new evidence or changes in perspective.
2017	a) According to the science community, scientific knowledge is accurate and can be trusted.
	b) According to the science community, scientific knowledge can change in the light of new evidence.

We argue that the two 2017 items have face equivalence with the nature of science item in the 2015 study. The second clause of the 2015 item is kept for 2017b. However, 2017a restates the durable nature of science as science being accurate and trustworthy. The durable nature of science implies its accuracy and thus trustworthiness. The obvious differences are that in the 2017 replication, students responded separately to each part of the 2015 item, and 2017a brings greater clarity to the concept of durability by substituting words having to do with accuracy and trustworthiness.

Comparison of Samples: Tests for significant differences between 2015 and 2017 indicate that the students in both years responded similarly, with noteworthy exceptions.

Confidence means between 2015-2017

	Year	N	Mean	SD
Motion	2015	297	4.48	.78
	2017	202	4.49	.79
Warming (climate change)	2015	303	3.89*	.99
	2017	202	4.08*	.95
Evolution	2015	298	4.19	1.01
	2017	201	4.11	1.10
Heart	2015	301	3.76	1.24
	2017	199	3.67	1.21
Science durable but can change	2015	296	4.42**	.84
Science can change	2017	194	4.73**	.54
Science durable but can change	2015	296	4.42**	.84
Science accurate & trustworthy	2017	195	3.37**	1.09

* Difference is significant at the 0.05 level (2-tailed). ** Difference is significant at the 0.01 level (2-tailed).

The mean of responses on the climate change item was higher in 2017 than in 2015, and this move is in a favorable direction as far as public confidence in science. The increase was statistically significant *(t(503)=2.133, *p*=0.033); however, the practical difference is small, with both years affirming the climate change statement.

One surprising result was the persistently low score on the heart item, in fact, there was no statistical difference between the 2015 and 2017 data on this item. Our study posited that this was one of two non-controversial concepts from science and thus we had expected results more like those for laws of motion (high means with low standard deviations). We concluded that the consistently low means and high standard deviations for the heart item suggested many students had much weaker knowledge in this area. That being the case, we dropped the heart items from the balance of the analyses.

We first made the assumption that the 2015 nature of science statement was primarily about its second clause, the changeable, tentative nature of science, and thus we compared it with the equivalent 2017 statement. Here too, there was a statistically significant increase **(t(487.805^{+})=4.970, p<0.001). However, though positive, the practical differences are again not large given that students in both years strongly affirmed the tentative nature of scientific knowledge.

The most surprising result from 2017 was how low students rated their confidence in the accuracy and trustworthiness of science, a precipitous and statistically significant drop from the composite item used in 2015 that mentioned durability **(t(341.656^{+})=11.396, p<0.001). This loss in confidence between the composite item (durability) and the dedicated item (accuracy and trustworthiness) is also significantly greater than the contrasting rise in apparent confidence that science can change.
($^{+}$equal variances not assumed (Levene's test))

The tables below show the correlations between items in 2015 and in 2017.

Correlations between confidence responses for 2015

		Motion	Warming	Evolution	Changes
Motion	Pearson Correlation	1			
	Sig. (2-tailed)				
	N	297			
Warming	Pearson Correlation	.220**	1		
	Sig. (2-tailed)	.000			
	N	296	303		
Evolution	Pearson Correlation	.045	.183**	1	
	Sig. (2-tailed)	.441	.002		
	N	291	298	298	
Science durable but can change	Pearson Correlation	.185**	.232**	.095	1
	Sig. (2-tailed)	.002	.000	.106	
	N	290	296	291	296

** Correlation is significant at the 0.01 level (2-tailed).

Correlations between confidence responses for 2017

		Motion	Warming	Evolution	Trustworthy	Changes
Motion	Pearson Correlation	1				
	Sig. (2-tailed)					
	N	202				
Warming	Pearson Correlation	.004	1			
	Sig. (2-tailed)	.950				
	N	200	202			
Evolution	Pearson Correlation	.039	.228**	1		
	Sig. (2-tailed)	.586	.001			
	N	200	199	201		
Science accurate & trustworthy	Pearson Correlation	.111	.088	.158*	1	
	Sig. (2-tailed)	.123	.224	.028		
	N	194	193	193	195	
Science can change	Pearson Correlation	.122	.184**	.084	.098	1
	Sig. (2-tailed)	.092	.010	.247	.175	
	N	192	192	192	194	194

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

All correlations found in the data were *positive*, with no inverse relationships. In 2015, confidence in climate change science correlated strongly with confidence in all other scientific statements, and confidence in Newton's First Law also correlated strongly with confidence that science is durable yet can change. In 2017, confidence in evolution correlated somewhat with confidence in the trustworthiness of science, but strongly with confidence in climate change science. Confidence in climate change science also correlated strongly in 2017 with confidence in the changeability of science. Curiously, positive correlations between confidence in climate science and in Newton's First Law went from statistically significant in 2015 to nonexistent in 2017.

Discussion of Findings

We used simple statistics (comparison of means and correlations) to explore the quantitative data with respect to our hypotheses. The comments made by students were categorized keeping in mind our interest in evidence that students have reflected on the association of confidence in scientific ideas in balance with the inherently tentative nature of science.

> **Hypothesis:** Students have confidence in the veracity of scientific concepts even if they have doubts about some areas of science such as evolution or climate change.

The good news is that all of the item confidence means are on the positive side of the Likert scale, even for the problematic item on the heart. Means for confidence in the science of evolution correlate strongly only with climate change and not at all with Newton's First Law. This suggests that those who were less affirming of the controversial science still affirmed the non-controversial science. This finding is consistent with other findings in the literature that people tend to be generally supportive of science even when there are aspects of science that they dispute. On the other hand, the *overall* means for confidence on "controversial" climate change science correlate (with statistical significance) with all other statements, suggesting that climate skepticism might correlate with weaker confidence in science.

> **Hypothesis:** Students *less* confident about the veracity of controversial concepts are likely to be *more* confident that scientific knowledge is tentative.

The second hypothesis is central to the purpose of this study. We were concerned that teaching the tentative nature of science could inadvertently undercut confidence in science. We examined that concern in our research by looking at the relationship between confidence in controversial concepts versus confidence in the tentative nature of scientific knowledge. The news is both good and bad. In 2017 the strongest statistically significant correlation was *between* confidence responses for the two controversial topics of evolution and climate change, $r(196)=.228$, $p=0.001$. The next statistically significant correlation, between confidence in climate change and confidence in the tentative nature of science was *positive*, $r(191)=.184$, $p=.010$, followed by a *positive* correlation between confidence on evolution and on the accuracy and trustworthiness of science, $r(192)=.158$, $p=.028$.

We further examined the relationships between the controversial items and the trustworthiness and tentativeness of science by breaking out the means for those students showing high and low confidence with regard to the two controversial areas. Interestingly, the percentages do not change much over the two years of data collection. Over both years, more than 70% of students indicated high confidence (4-5) in both the evolution statement and the climate change statement, while fewer than 10% of students indicated low confidence (1-2).

The following tables show two ways for comparing NOS confidence means between groups with low and high confidence in controversial science statements.

Comparing NOS confidence means between groups with low and high confidence in controversial science statements-1

			N	Min	Max	Mean	SD
Evolution	Low (1, 2) confidence	2015 Science durable but can change	20	1	5	4.25	1.07
		2017 Science accurate & trustworthy	19	1	5	2.89	1.10
		2017 Science can change	19	3	5	4.68	.58
	High (4, 5) confidence	2015 Science durable but can change	236	1	5	4.44	.84
		2017 Science accurate & trustworthy	150	1	5	3.44	1.09
		2017 Science can change	149	2	5	4.74	.55
Climate Change	Low (1, 2) confidence	2015 Science durable but can change	25	1	5	4.16	1.28
		2017 Science accurate & trustworthy	13	1	5	3.31	1.03
		2017 Science can change	13	3	5	4.62	.65
	High (4, 5) confidence	2015 Science durable but can change	212	1	5	4.52	.72
		2017 Science accurate & trustworthy	147	1	5	3.45	1.14
		2017 Science can change	146	2	5	4.77	.51

Comparing NOS confidence means between groups with low or high confidence in controversial science statements-2

Nature of science statement			N	Min	Max	Mean	SD
2015 Science durable but can change	Evolution confidence level	low (1-2)	20	1	5	4.25	1.07
		high (4-5)	236	1	5	4.44	.84
	Climate change confidence level	low (1-2)	25	1	5	4.16	1.28
		high (4-5)	212	1	5	4.52	.72
2017 Science accurate & trustworthy	Evolution confidence level	low (1-2)	19	1	5	2.89	1.10
		high (4-5)	150	1	5	3.44	1.09
	Climate change confidence level	low (1-2)	13	1	5	3.31	1.03
		high (4-5)	147	1	5	3.45	1.14
2017 Science can change	Evolution confidence level	low (1-2)	19	3	5	4.68	.58
		high (4-5)	149	2	5	4.74	.55
	Climate change confidence level	low (1-2)	13	3	5	4.62	.65
		high (4-5)	146	2	5	4.77	.51

What strikes us about the data is the change in the response to the NOS statements between the two studies. The mean in the 2015 data for the combined statement on the durability and tentativeness of scientific concepts is fairly strong (4.42). But, in the 2017 data with the NOS statement disaggregated and divided into one statement about accuracy and trustworthiness and a second statement about change, the two means have diverged. The mean of confidence responses on trustworthiness drops (3.37) while the mean of confidence responses on the changeable nature of science rises (4.73). Indeed, in 2017 only one student out of 202 chose low confidence in the idea that science can change. This pattern is consistent for students with either high or low confidence in evolution and also climate change, they are all *more* confident in the tentative, changeable nature of science than they are in its accuracy and trustworthiness.

There is little difference on confidence in trustworthiness between students with low and high confidence about climate change; both groups also show about the same confidence in the tentative nature of science. Not surprisingly perhaps is the finding that students with low confidence in evolution are the *least* confident in the trustworthiness of science (2.89), even while their confidence in the tentativeness of science is as strong as for other groups (4.68). The *difference* in confidence in trustworthiness is most pronounced between students with the *lowest confidence in evolution* and all other students, with the first group's trustworthiness mean of 2.89 standing out as the only one falling below the midpoint of 3. In other words, students with the lowest confidence in evolution (1 or 2 [M=2.89, SD=1.10] versus 3, 4, or 5 [M=3.42, SD=1.08]) are [statistically] significantly less likely than all other students to find science trustworthy ($t(19)=2.014$, $p=0.045$).

It appears that all of the students have at least some confidence in the changeable nature of scientific knowledge, and it does not seem to have an inverse relationship with confidence in controversial science. However, the bad news is that student confidence in the durability, accuracy, or trustworthiness of scientific knowledge is much lower than expected, irrespective of their confidence in evolution and climate change science.

Student comments. The surveys gave students the opportunity to comment about each statement. Roughly half of the students did so at least once. Most of the comments referred to where the student had learned something. For example, students would say that they learned about Newton's first law in some particular course. A few students would say that something was well-established in science. For the controversial statements, about evolution for example, students would occasionally say that the data is not that strong in support of human evolution. Regarding anthropogenic climate change, some students would say that there are other reasons for climate change. One student notably commented on how durability and tentativeness are related to available data, and that some scientific ideas are much more certain than others. We continue to explore the hundreds of student comments.

Demographic data. The demographic data did not immediately indicate major differences, with one unsurprising exception. Students who indicated that they regularly attended religious services were those who showed less confidence in human evolution and anthropogenic climate change.

Conclusion

As noted above, it is intriguing that disaggregating the 2015 NOS statement would change the findings so dramatically. The data clearly suggests that all of the students have at least some confidence in the changeable nature of scientific knowledge. However, when durability is expressed as accuracy and trustworthiness, and this concept is separated from the tentative nature of science, confidence in the trustworthiness of scientific knowledge drops across the board. The uncomfortable possibility is that our speculation has specific substance: emphasis on and student commitment to the tentative nature of scientific knowledge may well be undermining their confidence in trustworthiness of science. We are not surprised that students showing less confidence in certain areas of science would be confident in the tentative nature of science while being much less confident in the trustworthiness of science. What is troublesome is that even high science confidence students are far less confident in the trustworthiness of science than in its tentative nature. While our findings are not conclusive, they compellingly suggest that these concerns merit further investigation.

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