

The Multiple Meanings of Tentative Science

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ABSTRACT: The notion that scientific knowledge is tentative is an important and often emphasized concept within the nature of science. Its meaning, however, can be described in many different ways, even by scientists, educators, and philosophers. Of greater significance to us is that, when referring to science as being “changeable” or “tentative,” our students can have specific misconceptions which contradict fundamental aspects of the nature of science. This research considers in-depth, qualitative case studies of 4 college learners enrolled in a physical science course which caters to the needs of preservice elementary teachers and emphasizes the nature of science, science process, and teaching methods. These learners each reflect upon various degrees to which science’s knowledge can be tentative or changeable, yet they each describe different and misleading interpretations of this concept. We argue that students’ use of a specific meaning of “tentative” is dependent upon their underlying epistemological standards for science. Thus, an apparently slight misinterpretation of science’s tentativeness on the part of a student may be indicative of a more fundamental misunderstanding regarding science’s way of knowing.

Introduction

To say that scientific knowledge is tentative or changeable is supposedly an important and emphasized aspect of understanding the nature of science (American Association for the Advancement of Science [AAAS], 1990; National Research Council [NRC], 1995; National Science Teachers Association [NSTA], 2000). Yet, the meaning of “tentative” in this context can have many interpretations, even by philosophers and educators of science (Alters, 1997; Lederman & O’Malley, 1990). If one begins to consider the nature of Popper’s science, which goes through evolutionary-like changes (1962), to the nature of Kuhn’s description of science, which undergoes revolution-like changes (1970), it becomes clear that the tentative aspect of scientific knowledge can, and does, have multiple interpretations.

A typical manner in which we envision the changing nature of scientific knowledge is succinctly described by the AAAS: “Change in knowledge is inevitable because new observations may challenge prevailing theories. No matter how well one theory explains a set of observations, it is possible that another theory may fit just as well or better . . .” (AAAS, 1990, p. 2). As advocated by AAAS and other

standards of science literacy, this concept is one which we hope our students eventually learn in during their educations in order to contribute to and understand society. It should at least be clear that scientific knowledge itself, since it is created by humankind and because it is always subject to testing, must always be open to the potential to change. Although easy to state, it is difficult to find students who comprehend and accept such a concept (Lederman, 1992; Lederman & O'Malley, 1990). Furthermore, exactly what is it that we wish our students to say when asked, "Does science change?" If they simply respond, "yeah, sure," are we to assume that they understand the tentative nature of science? If they begin to tell us more about their understanding that "science can change," what exactly is it that we wish to hear?

Further, one may even question the importance of this concept. It has been argued that the tentativeness of science's knowledge is often overemphasized at the expense the point that the knowledge of the natural sciences is very stable and reliable (Good, personal communication, November 2001). The point, and the potential conflict it suggests, is an important one. We argue, however, that it is crucial that the very basis of science is what is emphasized. That is, *why* has science been so reliable – so much so that we can use the laws of Newton which are hundreds of years old and apply them to a modern day launching of a probe to Saturn? We contend that scientific knowledge can be relied upon due to the fact that it *is* tentative. Within the science education community we continually are in question of our own knowledge, and thereby we continually test such knowledge. We have come to rely on scientific knowledge by virtue of the fact that scientific knowledge *is* tentative. These seemingly paradoxical conditions – tentative yet reliable – provide for the position of science as one of the greatest inventions of humankind. Even so, one can still pose the questions: How important is it that a high school student understands this tentative aspect of science? And, again, how deeply and to what detail must he or she understand the concept?

The research presented in this paper simply exacerbates an already difficult set of questions. We have found that learners can know that scientific knowledge changes, and they can apply this to many specific situations. But do they understand what it is that they are saying, and would they conceive of the tentative nature of science in all situations? Our work shows how learners can not only vary in whether or not they conceive science knowledge to be tentative in nature, but those who do state that "science can change" can hold a wide variety of significantly different meanings for this tentativeness, many of which represent fundamental misconceptions for this aspect of the nature of science. These misconception, we argue, are deeply rooted to a learner's understanding of science's epistemological stance.

Now that the reader has a small taste of what lies before her, she is invited to read on. We begin by considering what issues we, as "experts" (educators, scientists, philosophers, and the like) might weigh as we think about how scientific knowledge changes.

A few points from philosophy of science

We shall begin by sitting back into cozy armchairs in order to "do" philosophy. By our standards, we imagine the "doing" of philosophy as involving rich conversation, late at night, accompanied by wafts of smoke emanating from pipes. Occasionally we sip from small crystal glasses as we ponder ideas that are especially troublesome. As philosophers, we begin to think of not only science, but also the reality (or lack thereof) in which we live, the knowledge that we can produce, how can we produce such knowledge. We might begin to ask questions regarding the very nature of our existence and if we can know anything for sure. Many of us come to conclusions somewhere along the lines that, if there is some reality, we might never be sure if we are viewing it for what it is. Others may even go so far as to suggest that there can be no absolute form of reality. A few of us stir nervously in our seats as we consider this – taking another sip from our glasses or a long draft from our pipes – while a few others smile in delight of such a notion.

Let us not go too far astray, though. Instead, we simply try to tackle the question, "Does scientific knowledge change?" We feel better about ourselves in this case, because the answer is clear: Yes, science's knowledge changes. Look back into history and it is quite clear. The Earth is no longer at the center of the universe. Species change. Time is variable.

At this point, the conversation becomes more difficult. What is science's knowledge changing towards? Does it get closer to some absolute truth? How could we be sure? How is it that we know when to change our scientific knowledge? What mechanism is there for change? What kind of control do we have over this change?

We could try to answer these questions by referring to our science texts from our early days, before we ever considered taking up such vices as smoking, drinking, and philosophy. Perhaps when we were only 11 years of age, we read something about the "scientific method." Within this structured algorithm we could see that science began with a proposal, guess, or hypothesis. The hypothesis was tested. Evidence was weighed, and later we repeated the entire cycle. Clearly, science could change, because it always began with a proposal that we were never sure of. But in the end, were we ever more sure? At some point, did we ever get to an answer? Some suggested that we did – some texts even implied that scientific "laws" were so well understood that they were essentially immutable. This most certainly is too simplistic a manner in which to view the process of science. Even if it left open the potential for scientific knowledge to change in all cases (as we have seen it change historically), it never really described what we as students did in our laboratories or what we read scientists were doing in their pursuits. We know that scientists do not go into the lab, punch their timecards, and then open their lab notebooks to see which step of the scientific method they will be doing that day.

So how does scientific knowledge change? We could argue a variety of viewpoints on this, and most certainly we could entertain ourselves with a lengthy debate between such viewpoints. Some of us could be positivists and some could take the side of relativists and a few others could be instrumentalists, and on and on until all the "ists" were represented. Then we would take great pleasure in debating these ideas; and debate we would until the wee hours of the morning, and while having enjoyed ourselves, we would never get to the conclusion of this particular paper. For our purposes, let us just exemplify a few stances that philosophers, scientists, and educators could take regarding the tentative nature of scientific knowledge.

One view might be likened to natural selection. An explanation is continually used as long as it successfully describes observation of the natural world. At the same time, the explanation is continually under trial, continually tested, to see if it fits with existing data. Explanations "survive" as long as they can account for data of the natural world. They die, and are replaced by a more fit explanation, whenever they cannot account for occurrences of the natural world. In this way, scientific knowledge evolves in small, ever progressing steps. Ironically enough, the manner in which such progress is attained is by falsification of the knowledge that is least correct. This view is one that Karl Popper has advocated (1973, 1962).

Another view could still find significance in the testing of scientific explanation, but may suggest that it takes a greater upheaval before scientific knowledge can change. Instead of one falsification, it may take a great number of these. And furthermore, whole new ways of thinking about nature and about science itself may have to change in order for new explanations to be understood and realized. Change in science's knowledge, from this point of view, is largely painful. The world of science gets much more accomplished – filling in the details and piecing together loose ends – when these radical shifts do *not* occur. Rather than being a welcome change, this view of changes in scientific knowledge suggests that it is a painful adjustment in which new ways of seeing and studying the world must be thought of in order for science to proceed. This view of revolutionary change in science is similar to that of Thomas Kuhn and many who would later build on these philosophical ideas (1970, 1962).

Still another view might be seen as an odd compromise between the previous two. Imagine scientific change as taking place in small, evolutionary increments. In fact, imagine that they occur with regularity, simply as a result of new scientists entering the discipline, and old scientists, along with their outdated ideas, dying off. While similar to the proposition of Popper because such change could occur without changing the entire worldview of science, the idea is also similar to the notion of Kuhn in that the knowledge of science is determined by something other than the natural world. This position is often referred to as the Planck Principle, after the quantum physicist who remarked that scientists cannot often

change their ideas and beliefs, but that it takes a new generation of scientists to support a new set of ideas. Holton and Brush (2001) pose how this plays out in the history of physics in certain circumstances. Hull and colleagues even show how this applies, in part, to the Darwinian revolution in the mid-1800's (Hull, Tessner, & Arthur M. Diamond, 1978).

The point of taking these different philosophical stances is this: Even if we barely scrape the surface of the issues within the philosophy and history of science, it is clear that tentativeness in science is not a transparently obvious concept. There are multiple ways in which science could change, and multiple causes for such changes. While the views advocated by science education standards (AAAS, 1990; NRC, 1995; NSTA, 2000) are relatively straightforward in that they paint science as an endeavor which is always trying to collect more evidence and construct more accurate explanation, we should not be surprised if our students do not grasp the entirety of these concepts right away. In addition, perhaps the fact that we tend to reduce this concept to a very superficial description misleads ourselves and our learners that it is a brief, easy-to-understand idea. Can a student (at any level) understand the concept stated above by the AAAS, its complexities and its implications? If so, is his understanding too oversimplified? Will a learner take this (or any other) description of changing scientific knowledge and embellish or misapply it? Our data demonstrate that the answers to these questions may be more complicated than first imagined.

Methods

In this research, 4 preservice elementary teachers' conceptions of science were investigated via qualitative case studies. These individuals all were enrolled in a university physical science course aimed at providing physics and chemistry content knowledge, teaching methods, and nature of science instruction. These individuals participated in interview probes throughout the duration of the course's semester. In addition, both before and after the set of interviews, a brief questionnaire about the definition of science (Abell & Smith, 1994) and the Nature of Scientific Knowledge Scale (Rubba & Anderson, 1978) were administered to the case study participants as well as to all others enrolled in the same course. These probes provided data, yet their most important utility was to give specific points to discuss in interview sessions.

Within the interview sessions, these 4 learners were asked direct questions about the nature of science, but also were asked to respond to readings, answer questions about a video, reflect upon course activities, sort cards with terms describing science, and consider the curriculum and situations within hypothetical classrooms that they themselves could be teaching. The data and subsequent analysis of such were part of a larger study (Johnston, 2001) that looked at individuals' conceptual changes over the duration of the semester, resulting from having taken the particular course in which they were enrolled and as a result of specific prompts and interactions. However, that study found that these learners' conceptions remained mostly static. From this we concluded that this semester's worth of data could be used to show the overall nature of science conceptions that these learners possessed.

Data, in the form of interview transcripts and field notes, were analyzed via grounded theory (Strauss & Corbin, 1998) in order to find themes in the case study participants' responses that reflected their understandings of specific aspects of the nature of science. These themes were compared so as to trace any development of each participant's nature of science conceptions throughout the duration of the semester, as well as to show the distinctions between all participants' conceptions.

To make sense of each learner's conceptions of the nature of science as they developed, descriptive narratives and summative tables were created to document a researcher's interpretation of the data. These products and their explanations were then checked against the data in search of negative instances and elaboration. From this, the narratives and tables were revised. Then, the results of each case study could be compared to one another. Specifically for the purposes of this discussion, a comparison of how these four individual's described scientific knowledge in a variety of instances was made.

Results

The NOS conceptions of 4 learners probed turned out to be quite rich and elaborate. From responses to probes, each learner's general characterization of science and its tentativeness could be ascertained. Although these views were not completely consistent within each learner, there did exist very clear tendencies for each individual. The benefit (from the standpoint of a researcher) of having each learner with a different overall conception of science is twofold. First, it demonstrates quite nicely that there are many conceptions of science and its tentativeness to be had in the first place. Second, it allows us to demonstrate how a learner's conceptual framework is internally interactive; that is, the concepts that each learner considered were interdependent. This aspect of nature of science conceptions will be revisited in our discussion.

In the following sections, each of the 4 participants is described in detail, along with the general theme of her conceptions of how scientific knowledge changes. For each individual, a specific set of conceptions is described.

Laura: Naive realism

Laura is like many of our university and high school students. While she looks forward to eventually teaching upper elementary grades, she has a fair amount of "science anxiety" and she has felt more alienated from than invited into science classrooms. She sees the processes and knowledge produced within science as being straightforward. Most of Laura's reflection regarding the nature of science portrays it to be an endeavor which simply builds upon itself, most knowledge being already well established. Science itself is mostly a large archive of "knowns."

Laura tends to sit in the back of the classroom, attentive but inconspicuous during class. She performs well in the course, maintaining a 'B' average that matches the average scores of the entire class, but she has the low confidence in her abilities, especially in science. Reflecting on her previous experiences with science coursework, Laura admits that she can be "intimidated" (LaQ1) and "scared" (La1, p. 3) of the content covered in science courses, and she implies that she generally hesitates to take science courses. (She is only enrolled in this particular course because it fulfills a requirement for the elementary education program.) On the other hand, she has also taken some geology courses that she enjoyed very much and felt successful with, making her think that incorporating some geology at the elementary school level would be fun for her students as well.

Responding in the written questionnaire before any interview sessions, Laura notes explicitly that she is taking this course so that she "will know how to teach my future students what science is and how it works" (LaQ1), but this is a rare instance in which Laura emphasizes anything about the processes of science and the definition of science. In most other cases, Laura describes science in terms of what it knows, describing it as "the [E]arth and what it contains" or "what the world is made of and how it works." Laura is reflecting her own emphasis of science as being the knowledge that is generated by science. Even more specifically, Laura shows her own bias towards learning about Earth systems science rather than biological science or some other domain of science. These attitudes are similarly reflected in the first interview when Laura is asked to define science in an interview: "I always just think of the Earth and how it's made" (La1, p. 6).

In an interview session, some statements regarding the tentative aspect of science were discussed briefly. Laura, sounding unsure of herself, begins to indicate that there are many pieces of scientific knowledge that we have yet to figure out: "[W]e just don't know everything" (La2, p. 8). She discusses the idea that there are things that we do not know, rather than discussing anything about errors or tentativeness in what we already claim to know.

Since it was difficult for Laura to describe the nature of scientific knowledge in general terms, we looked to a textbook written by her physics professor. The textbook in astrophysics is briefly described, and she is asked about how sure we are of the knowledge that is in it, specifically the knowledge that we claim regarding the temperature of the Sun. "It's probably . . . pretty sure, because it's in the book I guess" (La2, p. 8). Laura is less hesitant about making this statement than she was in describing scientific

knowledge without any concrete examples. She suggests that having scientific knowledge written down makes it less likely to be changed than if it were not in a text. In general, Laura's descriptions suggest that, since we do not already "know everything," she still sees scientific knowledge as something which could continue to look for new information. At the same time, the scientific knowledge which is currently written into textbooks must only be recorded because it is well known and not susceptible to revision. Her basic stance seems to be that science can continue to add new information, but that the information that already has been gathered is largely static.

In a later interview session, Laura is asked to sort cards with terms on them in any arrangement that makes sense to her, and then to explain her arrangement. These terms include *fact*, *theory*, *experiment*, *observation*, *trials*, *hypothesis*, *law*, *variable*, *religion*, *science*, *truth*, *known*, *changeable*, *progressive*, and *stable*. (The same terms were used in the card sorts done by other case study participants.) One aspect of all of Laura's sorting tasks that is consistent is her omission of three terms: "stable," "progressive," and "changeable." The fact that Laura leaves them out seems to suggest that she does not actively consider what these terms, or their implication of tentativeness, have to do with science. So, even if Laura were to show a conception that scientific knowledge is tentative, it seems that such a description for science is not one that Laura considers to be pivotal.

Science is an important endeavor in Laura's perspective, since "we wouldn't even know what was around us" if we did not do science (La4, p. 4). Asked why it is important to understand such things, Laura describes that "I don't know. Just, for me, it's important just to know about what God's created for us . . . It's hard to understand it all, but I think [that it's] important to learn" (p. 4). In this light, Laura does not just view science as one way of forming an understanding the world and our place in it, but as part of *the* way of understanding the world.

One interview probe simply asked Laura to describe the definitions of *fact*, *law*, and *theory*. To Laura, a "fact" is "just something that we've found that is true . . . just a 'fact'" (La4, p. 6). When asked what example she can think of, she refers to the current (as of this particular interview) content of the class: electric and magnetic fields. She justifies this by describing "that you see it and that's how it works" (p. 6). What Laura did see in lab and describes as seeing are the effects of electric fields (forces exerted on pieces of aluminum foil and light bulbs emitting light) and magnetic fields (the deflection of a compass needle), but she still describes the fields themselves as the facts that are known. A scientific law, Laura admits, she does not really have any idea of, other than it might be "something you have to follow," seemingly suggesting the more societal definition of a law (p. 6). A scientific theory, however, is some kind of a "new idea" (p. 6) that is different from a law in that "everyone didn't just believe because . . . I guess [it] wasn't fully developed enough" (p. 7). Throughout these descriptions, scientific knowledge is described as either pieces of information which are virtually self-evident, or are simply adding on brand new pieces of information. Again, there is little depiction of change.

As a result of taking this physical science course, Laura notes that she sees science in more contexts than she did before. However, this perspective of science is consistently limited to the knowledge base of science rather than its process and way of knowing aspects. Science, to Laura, is the "things that we use everyday" (La7, p. 1) and "how the world works," including "how we move, live, and function" (LaQ2). In line with this idea, Laura's emphasis on what is important to know in science has to do primarily with scientific concepts and really understanding them.

The above descriptions of Laura make us characterize her as a *naive realist*. As Southerland and Gess-Newsome demonstrate (1999), many preservice elementary teachers have a tendency to view knowledge from this viewpoint, seeing knowledge as something which is "universally accepted and unchanging" (p. 139). What few hints at tentativeness that Laura did make were mostly suggestive that science could gather more information and add to its knowledge base. The concept that science's knowledge would ever need to be modified in any way was never considered. Most likely, there were others in the same class as Laura who held similar views, even though they were enrolled in a class that described explicitly the nature of science and the tentative nature of its knowledge. Our other three case

studies, on the other hand, each demonstrate an awareness that scientific knowledge can and does change. However, these conceptions are established upon very different bases.

Jamie: Tentativeness due to error

In general, Jamie is quiet, keeping a low profile both in and out of class. Her slight frame and careful persona enhance her quiet character. Jamie is careful in most everything that she says, often preparing her responses to interview questions with long pauses of thought. A consistent theme throughout Jamie's characterizations of science is that the process of science is analogous to learning. As such, Jamie sees the knowledge that science builds as being susceptible to error, just as humans are prone to be mistaken. Still, just as humans eventually learn from their mistakes and eliminate error in order to perform well on an exam, Jamie suggests that science eventually scores well on its final exams. That is, despite the fact that science can contain error in it, Jamie sees this as just part of a process that leads to immutable and correct knowledge in most cases.

Jamie was typically comfortable with the coursework, though she scored marks in the class that were slightly below the class average. In interacting with Jamie in interviews, however, she seemed to have a much greater capacity to understand difficult concepts than any of the other case study participants and certainly seemed to have more aptitude than her grade (a 'B') would suggest. Jamie was certainly a dedicated student, often spending extra time after regular interview sessions to review course materials, or even to review math principles and music concepts from other courses.

Jamie's desire to be a teacher has been partially supported by her working with and observing an excellent teacher at the kindergarten level. She describes how in that particular classroom, science was presented as something that children can do for themselves and have fun with – in fact, investigations were integrated into their playtime. This is contrasted to the kind of science education that Jamie experienced herself in elementary school: "We read from the book and answered the questions. That's all we ever did" (Ja1, p. 4). Jamie realizes that there is more to science than this, and that there is merit in teaching science in an interactive and fun manner. She anticipates that the activities and portrayal of science advocated in this physical science class will be the kinds of things she would like to use in her own classroom.

In the earliest interview sessions, Jamie begins to lay out her ideas about science and how it changes. From the beginning, her analogy of science-as-learning is explicitly stated. Jamie will readily agree that scientific knowledge could have error in it because, for her, this is all part of the learning process: "That's the first step, probably. You have an idea and then you go and share it with other people . . . And then they can work together as a group and somehow make that knowledge into a law . . ." (Ja2, p. 4). Once such knowledge attains that status of "law," Jamie feels that it should not have any error in it. The idea of scientific knowledge as tentative is agreeable with Jamie, so long as the knowledge itself is somehow still under development. Once it reaches some mature stage – what she refers to as a "law" – it should no longer be mistaken.

In a later interview session where she is describing her card sort, Jamie discusses the process of science and how such a process involves laws and theories. She sees these two concepts as being different steps along a progression:

Jamie: So you can have a theory and it becomes law.

Adam: Okay. Once you get to a law, then what can happen? Or is it done?

Jamie: I thought it was done . . . because you have to, he said, you have to go to a board of scientists or whatever and they decide. (Ja3, p. 5)

In class it had been suggested that laws and theories were similar to one another in that they were testable but represented a very strong explanation (rather than a speculative one) of how nature operates, based on evidence. Jamie recites what was stated in class but adds a statement: "A theory becomes a law," as though it is a different kind of entity or stage. Further, Jamie suggests that laws are not tentative, referring to some board of scientists that decide what becomes scientific law. In class, it was noted that science was not a process of one individual, but was pursued by many individuals who communicated

with each other via journals, conferences, etc. in what is referred to as a “communal experience” (FN03.1). Jamie pictures this scenario as some committee of scientists who pass judgement on explanations, deciding whether to grant them the status of “law,” and thus something that is no longer tested. As she organizes the cards with terms on them, Jamie makes a conscious distinction between scientific “laws” and other constructs: “Ohhhh . . . I should have put this [law] over there” (p. 6), away from anything that is associated with changeable.

It is interesting that Jamie associates “changeable” with science, but considers “law” to be so static. It appears that science does change and progress, but at some point Jamie sees this as reaching an ending, what she calls a scientific “law.” In this probe and others that analyze a learner’s distinction between “law” and “theory,” it is less important that they know all the details regarding the exact distinction between these, but very informative to see what other conceptions the specific uses of these terms can reveal. Her constructions and uses of “law” and “theory” are not simply impromptu descriptions, for she uses them repeatedly throughout the semester.

Throughout the entire semester of interview sessions, and reemphasized in the final interview, Jamie says that the purpose of science is basically to produce knowledge, providing explanations for those who want to know (Ja7, p. 7). In addition to this, Jamie suggests that the importance behind teaching science is not only to provide explanations and knowledge, but to give students skills in thinking and asking questions. These skills become valuable not just for conducting science, but in all thinking and problem solving. Again, using the analogy that science is a process of learning, Jamie sees science as a great tool for understanding and making sense of the world. Although such a tool could occasionally be used incorrectly or give false results, eventually these mistakes are corrected. With constant effort, eventually science should provide the correct answers. The assumption Jamie is making is that the natural world is explained through some kind of directly discovered method. Although we could mislead ourselves, eventually nature herself will be uncovered.

Michelle: Historical tentativeness

Michelle walks into class and promptly and quietly takes her usual seat towards the back of the classroom. Armed with a cup of hot chocolate from the student union, she looks prepared but casual, composed but flexible. Michelle is soft spoken and never speaks out in class. In fact, other than a streak of hair bleached to contrast her light brown locks, Michelle draws little attention to herself. Yet, her capacity and awareness of her capacity for science are very clear and perhaps worthy of some attention. Michelle “love[s] math,” and she professes a joy in taking calculus exams in high school (Mi1, p. 1). Likely the least apprehensive about science of all of the case study volunteers, Michelle sometimes notes that she is bored in class since she is familiar and confident with much of the material.

Such boredom, rather than the result of Michelle’s *not* wanting to think about scientific issues, is the result of her desire to better understand many wonders of nature. Michelle shows fascination for the natural world, revealing her intrigue for certain concepts during the interview sessions. These interests stem more from other media (mostly TV) than from the course. For example, when discussing the surface temperature of the Sun, Michelle segued into a question about lightening, asking if it could really be hotter than the surface of the Sun – such a fact amazed her and piqued her interest, as do others that she comes across. Michelle finds a great deal of merit in scientific knowledge: “I pretty much believe everything science says” (Mi2, p. 2). Many of Michelle’s interests in science are related to biology, though many of her greatest fascinations are with natural disasters, such as earthquakes and the possibility of an asteroid collision with the earth.

As she describes in the first interview, Michelle uses her previous experiences in science classes as well as her experience during the 1st week of this class to define what science is: “using data, experiments, and experience to determine how the world works around me” (MiQ1). In a subsequent interview, Michelle continues to describe science as a process. Like before, Michelle claims that science is all about “finding out about the world around you . . . using all of your senses, thinking a lot, figuring out things” (Mi1, p. 4). Asked, “Why do we do science?” Michelle begins to hit on a theme that will

become familiar throughout her interviews. The theme is that of *utility* – that, even though science is done because we are curious about the world and want to obtain a better understanding of it, ultimately such an understanding should be of some important human use. Quite justifiably, Michelle points out that there is “tons we don’t know”(Mi2, p. 1). The “tons” to which she is referring and most concerned about, however, have to do with “like if something is going to come and hit the Earth, we should know about it – you know, to survive things” (p.1). For subsequent probes, Michelle is asked to describe more about science and some of its attributes. When asked, “What is the importance of science?” Michelle, in typical form, says that science is “understanding the world around us, so that we can become more and more advanced” (Mi4, p. 3). As she explains her statement, Michelle describes becoming more “advanced” as meaning that we will be able to better survive – to fight disease, prevent disasters, and increase our ease of living. Michelle even emphasizes this as part of what she would advocate in her own classroom as the reason we need to do science: “[S]cience does everything in the world. . . . learning about diseases and everything like that, I think it’s really important to find cures . . . also I don’t want to get hit with some asteroid or have some huge ol’ earthquake that no one knew about” (Mi6, p. 7).

In a majority of instances, Michelle shows a very strong tendency towards suggesting that scientific knowledge is tentative. Her view of tentativeness is quite specific, however. Although consistently suggesting that science “is always changing” (Mi2, p. 3), Michelle considers this tentativeness to be a dying attribute of science. “I think [scientific theories] are changing, but I don’t think they’re changing as much, because we have much more technology” (Mi2, p. 5). Thus, it would seem that Michelle sees science as something which can and does converge on the truth of nature. Michelle further exemplifies this when she describes how creativity applies to explanations in science:

I don’t really agree with that [the idea that a scientific law expresses creativity]. I think that the . . . actual law doesn’t come across to me as being creative. But when I think about what went on behind it, like uh, just the main thought that brought it up – the hypothesis or whatever – that seems creative to me. But when I look at a scientific law, I don’t think creative. It’s a fact (Mi2, p. 3).

Michelle separates the scientific product from the scientific process by suggesting that only one of them, the process, is a human creation. The products of science, while before suggested to be tentative, are given to us by nature. One would suspect that such gifts must also be correct, or as Michelle refers to them, “facts.”

In her card sort, Michelle makes special mention of the following terms: “changeable,” “progressive,” and “fact.” As Michelle describes the terms, science is both changeable and progressive, and she implies that the two are synonymous. That is, if any change is to take place, it must be a progressive change: “If something’s changeable, then it’s going to progress – become bigger and better” (Mi3, p. 2). Becoming more correct, science ideally leads towards something that we find “in the book” (p. 3), what Michelle refers to (in this instance) as a “fact.” When pressed, however, Michelle distinguishes facts from laws by noting that facts are the more obvious and immediate observations that one can make: “A fact would be like, ‘this is a tape,’ and, ‘that color is red’” (p. 3). In comparison, laws give more general predictive descriptions of the world. At this point in her explanation, Michelle is asked which of these two science is most concerned with, and she replies that “science is going after truth, the truth about everything” (p. 3). In a later interview, Michelle suggests that there are pieces of knowledge that can be “proven” (Mi4, p. 5).

For Michelle, tentativeness of scientific knowledge is ascribed to historical and is mostly done away with in light of modern science and its use of technology. Since nature and its explanation are discovered directly, according to Michelle, this understanding of tentativeness is reasonable within her own conceptual framework. Furthermore, there seems to be a connection between the idea that science should have some specific, utilitarian purpose, and the fact that its tentativeness is only a historical issue. By perceiving science as a technological method of changing the world, there may be less room for any change in science. That is, if science has only to serve a specific job or purpose, then the entire notion of

tentativeness does not really come into play. Tentativeness is only important if science's purpose is purely for explanation, and this is not the case for Michelle.

Joni: Case specific tentativeness

Joni exhibits a contagious enthusiasm for science and learning. Upbeat and never lacking for words, Joni's personality produced enjoyable interview sessions, although her fast paced and plentiful words provided a formidable challenge for transcribing audiotapes. In class, Joni displays a similar enthusiasm and willingness to participate. Joni's enthusiasm was reflected in her performance in the course, as she earned the highest scores in the class of any student. Perhaps this fervor was especially applied towards the sciences: "I really enjoy science courses. . . . I think science is really fun and you can do a lot of neat things with it" (JoQ1).

Joni is always looking for ways to integrate different aspects of her life and different aspects of society. For example, Joni tries to bring together descriptions of different school subjects, incorporating health issues with scientific ones, and describes how religion and science can be incorporated to produce a single, personal understanding of the natural world and of our existence. Joni considers teaching at a variety of levels but generally describes the desire to teach upper elementary levels. Quite enthusiastic about what she learns in this course, she is very excited about giving her own students a similar, hands-on experience in the classroom. She wants to show how science is related to students' lives, especially as it relates to health and the human body and to students' immediate surroundings.

Although Joni's first response to "what is science?" or similar probes is typically a response that suggests how science is a way to understand something, Joni is quick to follow up on this and emphasize that science will "improve the quality of life" (JoQ1) or will "make our lives easier" (Jo1, p. 7). Joni knows (or at least claims) that science is a means of understanding, yet she understands it to have a very definite purpose. That purpose is a pragmatic one, reflecting that science should produce some kind of useful result. Joni seems to be able to incorporate this purpose of science with her more formal definition of science: "Science explains things that I do all the time" (Jo1, p. 11). The emphasis here is that science could explain for Joni how to cook certain things or to help create things that are useful in our everyday existence. In a subsequent interview, Joni continues to describe science in a similar light, more explicitly than before:

You need to have your priorities straight in science, like what things need to be dealt with first, like where the money needs to go. Like I sometimes think, well maybe you should take the money from the space project and put it more in . . . cancer research; or, age research; or, something that can help the people here and now. . . . And science's [greatest benefit is in] helping people. (Jo3, p. 5)

In interview sessions and preliminary instruments that asked about the nature of scientific knowledge, Joni shows a strong agreement with the idea that scientific knowledge is tentative. Joni elaborates on this and makes her views more clear, describing scientific knowledge as something which is subject to change. At first (and second) glance, Joni's conceptions are what we, in science education, hope them to be, yet in clarifying and exemplifying her understanding more clearly, it becomes evident that the "tentative" aspect of scientific knowledge has a very specific meaning for Joni:

I think some of the things [scientific knowledge] are beyond doubt. . . . Like some of the laws, like gravity. . . . but there's some things like evolution theory, and . . . natural selection. . . . well, some of those things might be proven, but I think there's some doubt. (Jo2, p. 8)

Ironically, that which Joni imagines we understand "beyond doubt," such as gravity, may in fact be the least well-understood concepts in all of science. Joni is reserving the idea of tentative knowledge for that which seems less agreeable or likely to her, rather than as a facet of all scientific knowledge.

As with other case study participants, Joni's conceptions of "fact," "law," and "theory" reveal more about what she thinks of science than do they give us clear definitions of these particular terms. Joni, upon being asked how to define these, immediately wants to go back to her class notes to get the

correct definitions, but she tries it on her own anyway. “Off the top of my head, [a fact] would be something that’s been proven so much over and over and so much a part of our everyday life that no one would challenge to say it was incorrect” (Jo3, p. 8). When asked for an example, Joni suggests “gravity.” Scientific laws and theories are more intimidating for Joni, and she starts by noting that in class they were described as virtually the same kind of thing. Joni compares these to facts, noting that “laws are something that no one has been able to prove wrong [even though] they’re continuing to try; . . . [whereas] facts, maybe people stop testing them” (p. 9). Joni contrasts her present concepts of these terms to how she otherwise would have thought of them, laws as being “more absolute” and theories being more speculative. But she has an awareness at least that theories are “in the same world [as] laws” (p. 9).

For Joni, it is easy to describe the interaction between science and religion. These interactions can play out in different ways. One example:

A lot of stuff that I’ve learned [in science] really coincides well with what I believe; just how [everything] was created with different masses and everything. So, it could be created 6 million years ago, even though our Earth is only 6000 years. . . . So that’s just how it all works out (Jo4, p. 2).

Although it is not exactly clear as to how scientific knowledge really coincides with Joni’s religious beliefs (since scientific knowledge would not date the beginning of everything as occurring only “6 million years ago”), she feels confident that it does. She also sees this integration with others around her, describing doctors and professors who are in leadership positions in her church (Jo4, p. 5). Joni imagines that scientists integrate their scientific knowledge into their religious beliefs as well: “. . . after [scientists] see science, they can see ways that it works with their religion” (p. 7). Thus, not only for herself, but in all cases, Joni views the knowns of science and religion as working together towards one way of understanding.

In other instances, Joni tries to compromise science when there is specific conflict between its knowledge and the beliefs of her religion. Whereas in previous interviews Joni was quite clear that “theories” are valid scientific constructions, she changes her tone when she is asked to consider how to treat a circumstance in which a student protests the explanation posed by big bang theory:

I’d just tell them that there’s, that just because it’s a theory, it’s not a fact yet, but it’s been tested for a long time, but in a way that it could fit together with their church. [They can] believe how they believed, and they could take the knowledge that was in the book as they wanted to take it. There’s no one forcing them to believe in the theory of the big bang. (Jo5, p. 5)

Joni’s personal tactic of integrating her knowledge of science with her religious beliefs is something she advocates for others as well. This is not so surprising in light of other probes. What is surprising is that Joni describes big bang as “a theory, [but] it’s not a fact yet,” suggesting that theories are these speculative and not-well-understood nor important facets of science. Although this may be a relatively typical view, it is not the view that Joni suggests in other probes, such as the card sort. When faced with a direct conflict between her beliefs and the knowledge produced by science, her elicited view of scientific knowledge changes radically.

Overall for Joni, science is tentative. However, on this point Joni can contradict herself with other, overriding conceptions. Some scientific knowledge (Joni’s example is gravity) seems well accepted and beyond doubt, and thus nontentative. Other things can be directly observed and unquestionable. In these cases Joni confuses the purpose of science to be for solving problems rather than for giving deeper explanations of the natural world. Additionally, it could be that Joni’s want for science to be useful would require her conception of science to have some definite, nontentative truth that could be relied upon. We also see in Joni’s case that aspects of science become especially tentative when they are, on a personal level, controversial. Creating this controversy is the fact that Joni can suggest many examples of how science and religion can fit together to produce one cohesive body of knowledge.

Therefore, when a piece of scientific knowledge does not correspond to a religious belief, she actually uses the latter belief as a falsification for the scientific knowledge.

Discussion

Each of the case study participants, at one time or another, gives an indication that she views scientific knowledge as being tentative in one way or another. However, as the data demonstrate, this has many meanings. The definition of tentativeness that we may be striving to relate to students (that scientific knowledge should always be testable and could always be falsified in light of new evidence) is not necessarily the definition that a learner understands, even when she states that "scientific knowledge can change." This was similar to the work of Lederman and O'Malley (1990), who found that high school students could reflect an understanding of the tentative nature of science when asked about it in a questionnaire, but would represent this tentativeness in limited ways when they were subsequently interviewed.

In this research, each learner has a specific understanding of the tentativeness of scientific knowledge, whether or not she is conscious of her specific understanding. Laura, our naive realist, viewed knowledge and the natural world as having nothing to hide from one another, so knowledge could just be incrementally built upon, rather than modified or restructured. Jamie, equating science with learning, viewed tentativeness of scientific knowledge as an acceptable consequence of the possibility of making mistakes in any human endeavor; yet eventually mistakes can be completely corrected and science, like learners, will get the right answers. Michelle viewed tentativeness from a historical perspective, considering that there are many examples where scientific knowledge has been proven wrong in the past; yet Michelle was less accepting that the scientific knowledge currently produced is equally susceptible to falsification. Joni viewed scientific theories as being most tentative when the theories cannot be incorporated into religious beliefs, while other scientific knowledge (e.g., gravity) is viewed as well understood and not likely to be susceptible to change.

What we witness in looking at the multiple views of what "changeable" or "tentative" scientific knowledge is that this particular concept is problematic not only because a student may not be aware of this aspect of science, but because she can easily misinterpret this aspect. Even if a learner were taught explicitly that "scientific knowledge is tentative," this could be construed in a wide variety of ways, as is documented above. All of the learners in this case study may be able to associate scientific knowledge with "changeable," but what this means is not exactly what is strived for when we imagine someone who fully understands NOS concepts.

In science conceptions in general, this misinterpretation of a scientific concept is seen quite often, so it is perhaps not too surprising that we should also witness this in the case of NOS conceptions. For example, young learners may be able to state that the "Earth is round," yet this "roundness" can be represented in a number of ways. Also well documented in the literature (summarized by Driver et al., 1994), elementary and high school students have a difficult time coming to the conception that the tilt of the Earth's axis of rotation is responsible for seasonal changes; but, in addition (according to the first author's experience in teaching astronomy to undergraduate students), even when learners state that the seasons are caused by the Earth's tilt, they can still attribute the ultimate cause of seasons to one of two possibilities. One possibility is that such a tilt determines the angle at which the Sun's rays are directed towards a specific hemisphere of the Earth. This is the correct, scientifically acceptable understanding. However, even students who say that "the Earth's tilt creates seasons" can still be misunderstanding the concept, because they see this tilt as making some parts of the Earth closer to the Sun (and thus warmer) as compared to other parts of the Earth. In other words, in multiple instances we find students who can recite an appropriate answer, but their understanding of this answer is not what is being strived for in science education reform (AAAS, 1990; NRC, 1995). As described in the results, this happens with the statement versus the understanding of "science is tentative" just as it happens with other, more traditional science concepts. In all such cases, it is difficult to determine if the partial misconception completely inhibits a conceptual change toward the scientifically accepted conception, or if the partial misconception

is an appropriate step towards the development of the scientifically accepted conception. The latter situation has been documented in the work of Demastes-Southerland et al. (1996), though, in the case of this research, we would argue that learners tend to experience little, if any, controversy with their existing conception of tentativeness, so they have no catalyst to promote a change in their ideas.

To us, the most notable aspect of this research is the fact that these conceptions of tentative science are not islands unto themselves. Instead, they are deeply tied to other concepts regarding the nature of science. Past experience could already tell us that students have difficulty pinning down the exact meaning of "tentative" in reference to science knowledge. Our data expose an important facet and potential cause of this: Students develop or apply differing forms of "tentative" to science in order to coincide with the epistemological standards they associate science to have. For example, the individual who views science as being historically tentative does so because she understands that the knowledge of science is discovered directly by observing nature. From this epistemological stance, it is sensible to assume that science knowledge will become less tentative as we continue to observe nature more and with greater technological prowess. In a similar vein, the individual who applies "tentative" only to specific aspects of science typically does so as a result of comparing important parts of her belief system to specific scientific knowledge. Through such a comparison, scientific knowledge must be seen as tentative because it contradicts her own view of reality. In this case, because she overlaps the ontologies and epistemologies of science and religion, her view of the tentative nature of scientific knowledge develops a specific character.

These examples imply that by teaching the tentativeness of scientific knowledge, we might be missing a more fundamental concept. We argue that students must understand more of the epistemological background of science before science's tentativeness can be understood and appreciated in the appropriate manner. Similarly, other concepts within the umbrella of the "nature of science" may be better understood if learners can consider them after developing a deeper understanding of the production of knowledge in general and, more specifically, the production of scientific knowledge. If a student does not understand these, then there is little hope for full understanding of other nature of science concepts, such as tentativeness. However, science educators such as ourselves continue to look at nature of science as a compilation of a great number of individual ideas (see for example, McComas [1998]), rather than an all inclusive set of interdependent ideas that have a specific relation to one another. For example, it is *because* science's knowledge is constructed by humans (while at the same time based on empirical data) that it *must* be tentative. The epistemological basis of science determines what the nature of science will be. Should students understand more about such basis? If they do not, will they ever really understand the nature of science?

We, and perhaps the reader as well, are actually scared of our own suggestion. If we *do* need to teach about epistemology and knowledge in a more general manner before we can expect students to learn about other specifics within the nature of science, are we ever going to attain true science literacy? In his doctoral defense, the first author suggested that students may have to go this very route – he was practically laughed out of the room as a consequence of the suggestion, since it seemed like such an impracticality. It would require significant change and upheaval in our current educational system if we were to require all students at the university to take an "Introduction to Epistemology" course. Furthermore, one might wonder if this is a course that could be taught in one semester.

Perhaps the issue is less a matter of "what" we teach, and more of "how" we teach. Johnston (2001), in addition to Ackerson and Abd-El-Khalick (2000), shows how conceptual change teaching and learning strategies can make a learner more aware of his own existing NOS conceptions and thus more awakened to the fact that they may be different than the conceptions being advocated in a classroom. The problem, however, may be that it is easy for one to be satisfied with her conception of tentativeness, because it may seem so obvious. Science changes. Each of the case studies above would agree with such a statement, even though they had widely differing views as to exactly what this means. Perhaps conceptual change strategies can somehow become even more sophisticated, so as to alert learners to all the details of scientific knowledge and that which makes it tentative.

Another potential solution to the problem of tentativeness would be to eliminate this conception's importance in our standards altogether. We cannot begin to take such a suggestion too seriously, yet we also take away from this research that it is not completely clear what it is that we really want our students to know about the tentative nature of science. We do know that we want them to have a concept that is deeper and more elaborate than simply, "science changes." On the other hand, it seems too much to ask for even a sophisticated undergraduate or secondary teacher to fully understand the underlying philosophical problems, much less a high school science student. Is there a specific conception in between these two extremes for which we should strive? For us, this question remains unanswered.

Conclusions

In this research, we show that it is not only the statement that "scientific knowledge is tentative" that is important to look for when interviewing students, but also the meaning behind such a statement. Because "science," "knowledge," and even "change" can each have their own meaning, so too can this statement regarding the nature of science. But what does this leave us with? We contend that there are two important aspects of this research that should be more deeply considered.

First, we are left to wonder exactly *what* do we want our students and teachers to know about the nature of science, specifically the tentativeness of scientific knowledge. Do we want them to simply understand that it *does* change, that it *will* change in the future, or that it *has* changed in the past? Certainly, a learner may readily acknowledge one of these changes without recognizing the others. Similarly, what do we want our students to understand about the reason behind science's tentative nature? If we do not teach them anything in this regard, then learners are free to construct this aspect of the nature of science in whatever way they choose, either consciously or unconsciously. If we do teach them something in this regard, to what extent do we dive into philosophical discussions regarding the very epistemological underpinnings of science? And, where would such a discussion start? Exactly how important is it?

Second, we suggest that giving students some background regarding the epistemology of science *is* important. (Exactly *how* important and *how* involved such a treatment should be is unresolved for us, however.) We argue that to understand specific aspects of science, the nature of science, and specifically the tentative nature of scientific knowledge without understanding more fundamental issues about the source of scientific knowledge is simply nonsensical. Just as with the knowledge of science, any aspect of the knowledge of an individual learner must fit into a broader conceptual framework. The learner must see how all the pieces fit together. If the tentative nature of science is not given a rationale, then it is simply an isolated fact, devoid of context and meaning. In these cases, learners will produce their own explanations and justifications for the change of scientific knowledge, and these explanations may simply reinforce each learner's misconception of what science truly is.

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