Steve Witzig
College Science Teaching group
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CoRe: Content Representation Tool
(Loughran, Mulhall, & Berry, 2004)

Big Ideas/ Concept:	**Scientific knowledge is tentative.**
1. What you intend students to learn about this idea	A common misconception is that science and the methods of science produce absolute truth. I want college students to understand why this is a misconception, and I want them to appreciate that scientific knowledge is subject to revision. McComas notes that "a hallmark of scientific knowledge is that it is subject to revision when new information is presented. Tentativeness is one of the points that differentiates science from other forms of knowledge" (1996). The *College Pathways to the Science Education Standards* (NSTA, 2001) address the nature of science and reiterate the ideas put forth in the *National Science Education Standards* (NRC, 1996) for teaching the nature of scientific knowledge, that science is a human endeavor, and that historical perspectives are important for students be exposed to, especially given that scientific knowledge is tentative.
2. Why is it important for students to know this	College students should understand that scientific knowledge is tentative. Wong and Hodson (2008) captured some reasons for this well in an interview with a scientist: "Teaching about NOS, he [a molecular biologist in the study] said, can attract more young people to science, especially the more able students, because "it conveys a sense of excitement through its emphasis on creativity an intellectual endeavor." This kind of understanding is also important for citizenship education because "it teaches students not to believe everything they are told and to have the confidence to work things out for themselves." We can think of no better justification for the curriculum we are developing" (Wong & Hodson, 2008, p. 19).
3. What else you know about this idea (that you do not intend students to know yet).	**WHAT THE STANDARDS SAY:** *Science for All Americans* (AAAS, 1990) states: 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, or may fit a still wider range of observations. . . .Most scientific knowledge is durable. The modification of ideas, rather than their outright rejection, is the norm in science, as powerful constructs tend to survive and grow more precise and to become widely accepted.

	Benchmarks for Science Literacy (AAAS, 1993) states: Scientific knowledge is subject to modification as new information challenges prevailing theories and as a new theory leads to looking at old observations in a new way. Some scientific knowledge is very old and yet still applicable today. *National Science Education Standards* (NRC, 1996) states: Although all scientific ideas are tentative and subject to change and improvement in principle, for most major ideas in science there is much experimental and observational confirmation. Those ideas are not likely to change greatly in the future. Scientists do and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations. *NSTA Position Statement on the Nature of Science* (NSTA, 2000) states: Scientific knowledge is simultaneously reliable and tentative. Having confidence in scientific knowledge is reasonable while realizing that such knowledge may be abandoned or modified in light of new evidence or reconceptualization of prior evidence and knowledge. **WHAT PHILOSOPHERS AND SOCIOLOGISTS VIEWS OF NOS/TENATIVE ARE:** Inductivists- Positivism/empiricism: "Scientific knowledge should be in some way be derived from the facts arrived at by observation. . . .Three components of the stand on the facts assumed to be the basis of science in the common view can be distinguished. They are: (a) Facts are directly given to careful, unprejudiced observers via the senses. (b) Facts are prior to and independent of theory. (c) Facts constitute a firm and reliable foundation for scientific knowledge" (Chalmers, 1999, p. 3). Falsificationism (Popper): "Falsificationists freely admit that observation is guided by and presupposes theory. They are also happy to abandon any claim implying that theories can be established as true or probably true in light of observational evidence. Theories are construed as speculative and tentative conjecture or guesses freely created by the human intellect in an attempt to overcome problems encountered by previous theories to give an adequate account of some aspects of the world or universe. Once proposed, speculative theories are to be rigorously and ruthlessly tested by observation and experiment. Theories that fail to stand up to observational and experimental tests must be eliminated and replaced by further speculative conjectures and refutations. Only the fittest theories survive. Although it can never be legitimately said of a theory that it is true, it can hopefully be said that it is the best available; that it is better than anything that can come before" (Chalmers, 1999, p. 60).

	Scientific Revolutions (Kuhn): "A key feature of his theory is the emphasis placed on the revolutionary character of scientific progress, where a revolution involves the abandonment of one theoretical structure and its replacement by another, incompatible one" (Chalmers, 1999, p. 107). Research Programmes (Lakatos): "Progress involves the replacement of a degenerating program with a progressive one, with the latter being an improvement on the former in the sense that it has been shown to be a more efficient predictor of novel phenomena" (Chalmers, 1999, p. 138). Anarchy (Feyerabend): "He has insinuated that there is no logic to science; scientists develop and adhere to theories for what are ultimately subjective and even irrational reasons. According to Feyerabend, there are no objective standards by which to establish truth. "Anything goes" he says" (Horgan, 1993, p. 36). "The theory we have chosen may be pretty lousy. It may contain contradictions, it may contain conflict with well known facts, it may be cumbersome, unclear, ad hoc in decisive places and so on. But it may still be better than any other theory that is available at the time. It may in fact be the best lousy theory there is. . . .The progress of science, of good science, depends on novel ideas and on intellectual freedom" (Feyerabend, 1975, p. 5,8). Sociology (Collins): "A crucial feature of this program of inquiry is the assumption that the ultimate answers to the questions are Nature's, mankind being only a mediator. Thus the proper institutional prerequisites must obviate the effect of mundane disagreements and biases. There must also be a reward system to encourage the vigorous pursuit of the answers" (Collins, 1983). Obsborne, Collins, Ratcliffe, Millar, & Duschl (2003) address the tentativeness of scientific knowledge in Figure 1 on page 700:

The tentative nature of scientific knowledge

Summary
Students should recognise that scientific knowledge is provisional. Current scientific knowledge is the best we have but may be subject to further change given new evidence.

Typical supporting statements
(a) Scientific knowledge is in a state of continuous change. Theories are the best we can do with the current state of knowledge.
(b) Theories can be falsified if wrong; they can be modified and extended if correct only in a limited region.
(c) That scientific knowledge is not fixed for all time because scientific ideas are adapted and revised in the light of new evidence.
(d) That scientific knowledge is tentative. Scientific knowledge depends on the available evidence and methods for gathering it. As technology makes more precision possible, so new evidence may be revealed, so ideas change. We should always regard scientific knowledge as the best we know at the moment and subject to change.
(e) They should be taught that scientific knowledge is the best kind of knowledge we have when it comes to understanding the natural world, but this does not make it perfect. They should understand that you have to get by with the best even if it is not perfect and often this will be scientific knowledge.

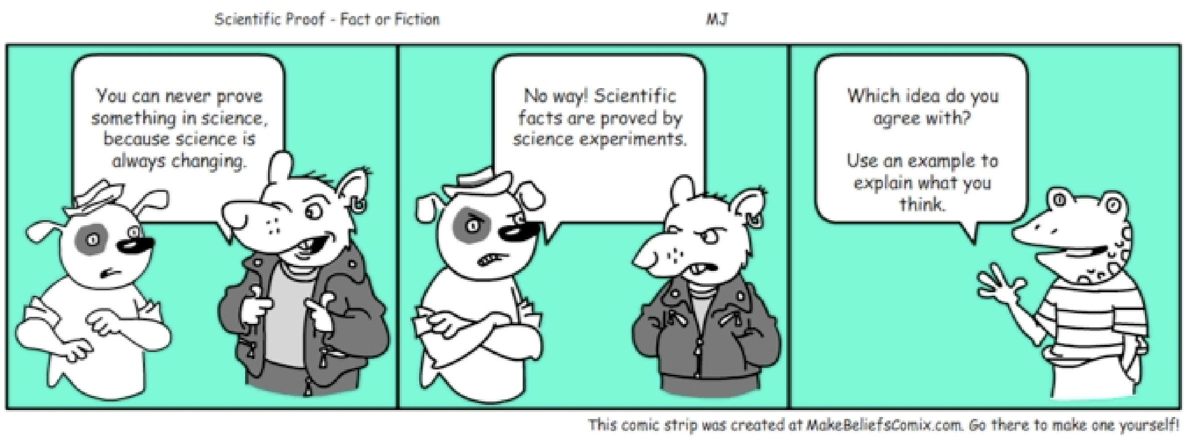
Figure 1. Justification of one theme from Round 1 and its presentation for Round 2.

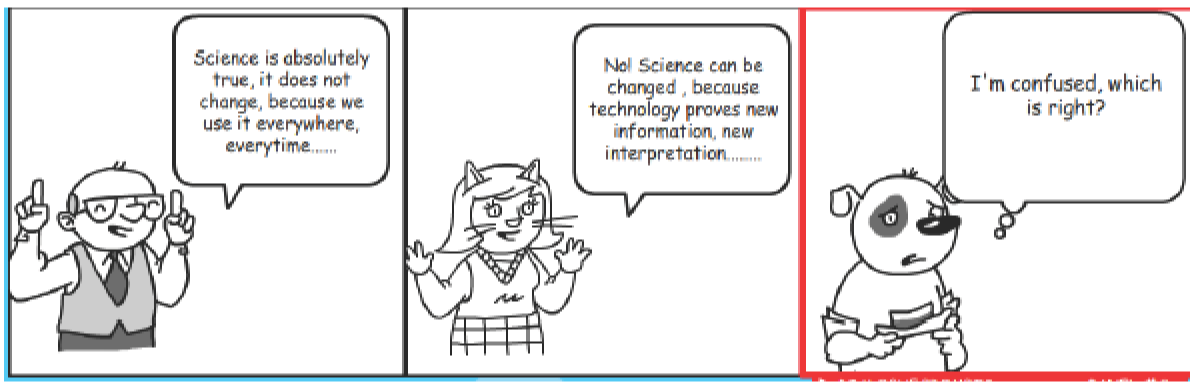
“What is needed is for educators to accept that no single nature of science exists and to develop curricula that help students understand instead the diverse, local practices that are found within and across scientific disciplines (Rudolph, 2000, p. 403).

	"One of the enduring goals of science education is the development in students of some understanding of the nature of science. That understanding . . . can only be found in the practice of science itself. As valuable as the varied grand philosophical, historical and sociological narratives might be, in the end, just as there is no non-empirical access to the 'real' world, there is no referent outside science itself that can provide a more authoritative picture of what science is in all its rich diversity. It seems it is there that understanding should be grounded, with each inquiry, case, or research programme providing the bound for what science is about in that particular instance, and with each instance building toward a greater understanding of not what science *is*, but rather what science *includes*" (Rudolph, 2000, p. 417). **What Scientists say about NOS and the tentativeness of scientific knowledge:** Wong and Hodson note, "We see another need to elicit scientists' views of the NOS: rapid advances in scientific knowledge and investigative procedures over the past fives, particularly in the biological sciences. . . .we believe that NOS understanding is as tentative and subject to change as scientific knowledge itself, and we question whether the consensual list of NOS elements any longer fully reflects 21 st-century scientific practice" (2008, p. 5). A scientist's view of the tentativeness of scientific knowledge: "These two theories [referring to *superstring* and *loop quantum gravity*] are well-established but tentative. Well-established in the sense that they have been around for about two decades and have still not been refuted by available data. Tentative in the sense that they are subject to change when more data reveal their inadequacy . . .other theories will emerge and replace the current ones when new experimental or observational data become available" (Wong & Hodson, 2008, p. 13). "They [the scientists in the study] were all adamant that all scientific knowledge, including "laws," is subject to modification when there is appropriate evidence and a convincing argument" (Wong & Hodson, 2008, p. 14). "They [the scientists in the study] seem be saying that while a detailed explanatory structure itself may be somewhat tentative and subject to elaboration and modification, the specific entities postulated with that theory have a real existence" (Wong & Hodson, 2008, p. 15).
4.Difficulties/limitations connected with teaching this idea	I don't think I will have a problem teaching this idea, though I think a barrier that I might face is making sure that the students learn it and appreciate its tenets. You can teach all you want, but teaching doesn't necessarily result in learning. My college students will most likely have been taught (whether explicitly or implicitly) throughout grade school (K-12) that science is a collection of facts to be memorized. To address this, I will use several strategies and assessments to teach the NOS (see below). I think that one of the biggest challenges will be to help the students overcome their misconceptions that science produces absolute truth.

5.Knowledge about students' thinking which influences your teaching of this idea	As mentioned above, McComas notes in "Myth 5: Science and its methods provide absolute proof [that] a hallmark of scientific knowledge is that it is subject to revision when new information is presented. Tentativeness is one of the points that differentiates science from other forms of knowledge" (1996).
6. Other factors that influence your teaching of this idea	Students will enter the college classroom with a range of experience with science, as well as from many different cultures, backgrounds, etc. I think it will be important to be sensitive to these issues when using examples in class and to create an atmosphere where discussion of potentially threatening topics (cloning, science vs. religion, evolution, etc.) proceeds openly and with respect of everyone involved. The 'New Society' example (below) will be a great way to start the semester off with how the class will proceed with discussions.
7. Teaching procedures (and particular reasons for using these to engage with this idea)	**Reasons to Engage Students with NOS ideas:** In order to effectively teach and engage students in science, science educators need to include the philosophy of science and the history of science into the discussion. In doing so, there is a need to humanize the enterprise of science. As was the case forty years ago for Elkana (2000), and ten years ago for Hodson (1998), I believe this still to be an important point/plea for the teaching of science today. As science educators, we need to move away from teaching science as a series of facts in an authoritarian manner, and move to incorporating a more authentic depiction of what science is and what scientists do. If teachers explicitly introduce NOS topics into secondary level classrooms that students may be able to make more sense of the science, and may be able to apply the content knowledge that they learn later on in their lives. The body of work reported included a synthesis of the NOS literature as it pertained to their study including ideas that we have addressed in class: induction, science as a social enterprise, science as being tentative, the role of experiments in science, etc. (Driver, Leach, Millar & Scott, 1996). As science educators it is important that we are aware of these types of research studies so that we can learn from them to inform our own teaching (and research) practices. The NOS can be taught through implicit (solely using hands on or inquiry-oriented instruction) or explicit (specifically addressing NOS views from a historical/philosophical perspective) approaches and can be integrated within the science content or not integrated (Abd-El-Khalick & Lederman, 2000; Khishfe & Lederman, 2006). The research shows explicit teaching of the NOS is more effective, whereas whether it was integrated into the content or not had little effect. These

	findings aligned with previous readings in the class that showed if teachers explicitly introduce NOS topics into secondary level classrooms that students may be able to make more sense of the science, and may be able to apply the content knowledge that they learn later on in their lives. As science educators it is important that if we want our students to understand and to be able to apply the science content that they are learning, then we should explicitly teach the NOS alongside or within the lessons. Though the research was done in secondary level classrooms, I don't think it would be a stretch to apply this idea to college level classrooms. **Teaching procedures:** On the first day of class, or at least the first week of class, I think using the 'New Society' activity (Cavello, 2008) would be a great way to introduce the NOS into my college classroom. It will not only introduce the students to NOS ideas, including tentativeness, but it will also create a social atmosphere in the classroom where the students are exposed to teaching strategies that not solely didactic. Afterall, science is social enterprise, so why not mirror that in the classroom? To specifically address tentativeness, I will use the following cartoons to engage students with this idea. 





These cartoons will be excellect converstation starters to help students make meaning of their understanding of the scientific enterprise. In addition to using these cartoons that are specifically designed to address the issue of tentativeness, I would start each lesson (or at least each lesson where it would be appropirate) with some popular images of science like we have in this course. I think they are great converstation starters and can really be used to ellicit student understading of the NOS. One thing I really like about using cartoons, is that you can use them in many different contexts and with many different audiences. The first cartoon above is the one that I developed. This can easily be used with a group of students for them to debate the ideas in the second and third panels. However, it can also be used with teachers if you have the teachers focus on the last panel. Here the teachers could brainstorm what they would do in this situation. This activity

	could enhance a teachers PCK in this area. Another strategy I will use is to have students read popular culture books/short stories about science and scientific processes. After reading Watson's (1969) book about the discovery of DNA I have to admit that I was embarrassed that throughout my educational training as a biologist and biochemist, I had not been encouraged to read this. I think this, and other books written by scientists, are just as important, if not more important than the traditional texts used in a classroom (textbooks, powerpoint slides, etc.). In fact, even using excerpts from the texts could be valuable. To address the issue of tentativeness in science, I could share the following statement from Watson: Many were cantankerous fools who unfailingly back the wrong horses. One could not be a successful scientist without realizing that, in contrast to the popular conception supported by newspapers and mothers of scientists, a goodly number of scientists are not only narrow-minded and dull, but also just stupid. (1969, p. 18-19) This quote can be used as an engage activity to have the students make meaning of what Watson is trying to say. Then, we can open it up for whole class discussion and if it does not come up in the discussion (which I doubt it would not), I could guide the students to talking about how this relates to the tentativeness of science. This could easily be organized as a Think-Pair-Share activity. The card sort activity (see Appendix A) would be another excellent activity to engage students about the scientific enterprise and the NOS. It think the card sort activity shortly after the 'New Society' activity would work really well to strengthen some of the students understandings of core NOS ideas.
8. Specific ways of ascertaining students' understanding or confusion around this idea (including likely range of responses).	Assessment of student learning is an essential component of teaching/learning. To specifically address students' ideas about the NOS, I will use the VNOS-C instrument and administer it at the beginning and at the end of the semester. This will allow me to track students' ideas about the NOS after our discussions. The V-NOS is well-tested instrument and there is a significant pool of literature about the range of participants responses. I expect that at the beginning of the semester, my students will hold the misconception discussed by McComas (1996) that science produces absolute truth. My hope is that by the end of the semester, the students will appreciate and understand that scientific knowledge is tentative. I feel that it is important to revisit ideas that you discussed earlier in the semester. One way I will assess students understanding is to present an idea (either orally or through written assignment), and have the students relate that idea back to the New Society or Card Sort activity that we did in week 1 of the semester. This bridging analogy activity will allow me see if the students are making the necessary connections required to understand not only the science content, but also the NOS and the enterprise of science.

	Some additional ways to assess students learning are to work the ideas into a game show format, like Jeopardy. I feel that learning should be fun, and this would be a way to make learning not only fun, but will allow me assess the students learning. I like the idea of using concept maps as well to assess students understanding. This would be a great way to see how the students are able to connect ideas related to the NOS. There is an online concept-mapping tool (http://cmap.ihmc.us/download/) that students could use to incorporate technology into the classroom. If this is not available, a concept map is simple enough to be a low-tech way to assess students understanding and they could just use paper and pencil.

Appendix A

Card Sort Activity: What is Science?

1. Cut the cards apart
2. Sort the cards into two piles: agree and disagree
3. Identify the cards in your agree pile by card number, then do the same for the cards in your disagree pile.
4. Compare your cards with a friend and discuss the choices you made.
5. Select 4 cards that you believe represent your thoughts about science.
6. Pick 4 cards that are not representative of science.
7. Pick cards from both piles to help you write a paragraph about the nature of science.

1. Science gets closer and closer to the truth.	8. Scientific observations of the same object or process leads to identical interpretations.	15. Science and its methods provide absolute proof.

2. Science and its methods can answer all questions.	9. Facts do not speak for themselves, they must be interpreted by theory.	16. Scientific concepts are discovered.
3. A scientist should not allow preconceived theoretical ideas to guide observation and experimentation.	10. Experiments are the principle route to scientific knowledge.	17. Scientists are particularly objective.
4. Careful observation gives us the truth about the world around us.	11. Science is one of several ways of knowing.	18. Historically, Science has been dominated by white Europeans and North American males.
5. Evidence accumulated carefully will result in knowledge.	12. All work in science is reviewed to keep the process honest.	19. Theories change when new conceptualizations account for anomalous data.
6. Hypothesis become theories, which become laws.	13. Theories serve to give direction to observations -- they tell one where to look.	20. Science deals with testable questions.
7. A general and universal scientific method is used by all scientists.	14. Scientific concepts are invented	21. What scientists choose to study reflect the social values and views of the time.

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