Review of Proposed Science TEKS by David M. Hillis, Professor, University of Texas at Austin

(1) Do the TEKS ensure that scientific concepts are presented in an accurate and factual manner?

For the most part, yes. The major exceptions are the following:

Some of the draft standards confuse the concepts of *scientific theories* and *scientific hypotheses*. The standards for the grade 9-12 Physics course — 112.47 (a) (2) — get it right: "A hypothesis is a tentative and testable statement that is based on observation. Students should know that scientific theories, unlike hypotheses, are well-established and highly reliable, but they will still be subject to changes as new areas of science and new technologies are developed." This is good, but additional explanation may be needed here, given the common misunderstanding of the meaning of *scientific theory*. Students should know that scientific theories are based on a huge body of scientific investigations, and that scientific theories represent scientific consensus based on an evaluation of the sum of scientific evidence (typically from hundreds of thousands of scientific investigations across many decades or even centuries). Moreover, scientific theories are predictive, and allow scientists to make both broad as well as specific predictions about the natural world. It is not sensible to imagine students at the high school level evaluating or critiquing the totality of the evidence that goes into a given scientific theory, given that scientific theories are based on such an enormous body of scientific evidence. On the other hand, students certainly should learn to evaluate and test examples of specific scientific hypotheses. But asking high school students to evaluate the strengths and weaknesses of Gravitational Theory, or Evolutionary Theory, or Plate Tectonic Theory is well beyond what is possible or reasonable or productive in a high school classroom. Such scientific consensus would not emerge unless the evidence were overwhelming, and high school students cannot possibly evaluate any reasonable proportion of the scientific literature in a given discipline.

In contrast to the Physics standards cited above, the chemistry standard — 112.45 (b) (3) (A)—clearly confuses these issues. Here the draft states that students are expected to "analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information." This, of course, is not possible in a high school course, and the statement confuses the meaning of "hypotheses" and "theories." This statement could easily be revised to: "analyze, review, and critique examples of scientific hypotheses as to their strengths and weaknesses using scientific evidence and information." That goal is reasonable and feasible. It would be better, however, to clearly

distinguish, as the Physics standards do, the difference in meaning between *scientific theories* and *scientific hypotheses*. The standards for most of the remaining classes do not confuse these concepts, with the exception of Astronomy—112.48 (c) (3) (a)—which makes the same error that appears in the Chemistry standards. The standards for the remaining courses are written in appropriate language to avoid any confusion. In fact, the standards in the Grade 7 Science course emphasize student-generated data to understand how specific scientific hypotheses can be tested. As students learn by doing, this approach is likely to help students understand the appropriate roles of hypotheses and critical thinking in science.

Other corrections to scientific concepts specific to individual courses:

112.43 Biology
112.43 (c) (6) (B) [The student is expected to:] *recognize that the genetic code is common to all organisms*;
This statement is false. The canonical genetic code is common to many, but by no means all, organisms, and there is no universal genetic code. Students need to know that all of life shares a similar genetic code, but that changes in the code have evolved several times over the course of the history of life. Even within humans, the genetic code for nuclear genes is not identical to the genetic code for mitochondrial genes. Students also need to understand the fundamental difference between the meaning of *genetic code* (how protein sequences are encoded in DNA) and a *genome* (the complete genetic sequence that makes up an organism). The genetic code diverges very slowly, although the genomes of different species diverge comparatively rapidly.

112.43 (c) (7)
In this section, the student expectations are all reasonable, but the applications of evolutionary theory are missing. Students cannot be expected to understand concepts without an understanding of their application. In virtually every other area in which a major scientific theory is presented (in each of the science courses), there are explicit student expectations to demonstrate to students how the theory is applied to important problems. This is important, because the applications provide the motivation for many students to learn about major scientific theories. I suggest the addition of the following student expectation in this section:

112.43 (c) (7) (F) [The student is expected to:] describe how evolutionary theory is applied to solve practical problems, such as problems in human health, vaccine development, agriculture, forensics, and production of novel pharmaceuticals.

112.43 (c) (8) (C) [The student is expected to:] *compare characteristics of kingdoms including archeobacteria, eubacteria, protists, fungi, plants, and animals.*

This statement is problematic for two reasons. First, there is no objective or consistent definition of "kingdom," and so this and other arbitrary taxonomic ranks are now de-emphasized or no longer used in biology. Second, even where the rank of "kingdom" is used in the biological literature, I am not familiar with any classification that treats the groups named in this statement as "kingdoms," especially since some of these groups are imbedded within others. They are almost all important groups on the tree of life that students should know about, but there is no information in using the term "kingdom," and indeed that is misleading since these are at different levels of any taxonomic hierarchy. I say "almost all important groups," because biologists now recognize that protists are not a valid taxonomic group. In addition, a critical group that students need to know about (eukaryotes) is missing from the list, despite the presence of "archeobacteria" (more properly called archea or archeans) and "eubacteria" (now known more widely simply as bacteria), which are at the same taxonomic level. To fix these problems, I suggest replacing the statement with:

[The student is expected to:] compare characteristics of major taxonomic groups of life including archea, bacteria, eukaryotes, fungi, plants, and animals.

The same problem is also found in the Grade 6 Science course:

Grade 6 (a) (3) (E): "concept of kingdoms" This should be replaced with "concept of the tree of life" ("kingdom" is a meaningless term, whereas the tree of life is an important and widely used concept in biology)

Grade 6 (b) (12): "All organisms are classified into Kingdoms." This should be replaced with "All organisms are classified into major taxonomic groups on the tree of life, which depicts the relationships among organisms."

Grade 6 (b) (12) (A): "identify the basic characteristics of organisms in the currently recognized Kingdoms" This should be replaced with "identify the basic characteristics of organisms in major taxonomic groups"

112.43 (c) (8) As with an earlier section, it is important for students to understand *why* they need to learn about biological classifications. If the applications are not included, then students are left to wonder why they spent time learning this material. For example, compare this section to 112.45 (c) (5) in the Chemistry course, where the Periodic Table is presented, and then its *uses* are listed. But when biological classification is presented in the Biology course, there are no uses included. This can be corrected by adding:

112.43 (c) (8) (D) [The student is expected to:] describe how biological classifications are used to organize and retrieve biological information and to make predictions about organisms throughout various fields of biology.

112.45 Chemistry
112.45 (c) (1) (B): Note accidentally repeated phrase
112.45 (c) (3) (A) Incorrect and misleading use of the word "theories" as noted above.

112.47 Physics
Except for 112.47 (c) (1), all of the "The student is expected to:" statements are missing from the Knowledge and Skills section.

112.48 Astronomy
112.48 (c) (3) (A) Incorrect and misleading use of the word "theories" as noted above. The statement could be corrected to read: "analyze, review, and critique examples of scientific hypotheses as to their strengths and weaknesses."
112.48 (c) (6) Parts (A) and (B) seem to be virtually the same expectation to me. Similar overlapping statements are found in Science Grade 6 (b) (11) (A) and (B), and it is unclear to me how these statements are meant to be distinguished.

112.48 (c) (7) I don't understand the statement "The student knows the role of the moon." What does "role" mean in this context? Perhaps this statement it is meant to say something like "The student understands lunar cycles and the interactions between the Moon and Earth"?

112.XX Earth and Space Science
112.XX (b) (2) (C) The statement "Fluid Earth interactions are responsible for Earth's past and present climate" is too absolute. Certainly, these interactions have an enormous influence on Earth's past and present climate, but are clearly not the only influences. This should be changed to something like: "Fluid Earth interactions are responsible for many major changes in Earth's past and present climate."

(2) Is a complete and logical development of scientific concepts for each grade level or course followed?

Yes, for the most part, except as noted in (1) above (where I noted that a few key concepts and some key applications of concepts are missing). However, this format for the standards forces one to imagine filling in a lot of gaps. The draft provides only a very rough guide to what will be presented, and I have to assume that teachers will have enough sense and training to provide all the background information necessary to develop the courses into a complete and logical sequence. The standards certainly do not identify all the concepts that need to be covered, but the document would have to be much longer and more detailed to correct that problem. Therefore, I assume that

this is meant as a guide to identify some highlights of critical concepts that need to be covered, rather than a comprehensive guide to a "complete and logical development of scientific concepts for each grade level." In my comments above, I tried to identify some major concepts that are missing, but I did not try to point out all the concepts that have to be covered as background. As an example, in Science 4 (7) (F), students are expected to "use models to observe fossils found in rock layers." If this is really the only activity that the students do, then they will learn almost nothing. But, I assume that this activity is identified as an opportunity to teach students concepts such fossilization, stratigraphy, geological dating, etc. (those concepts can easily be taught in Grade 4, especially since children of that age are easily excited by fossils, even though the terminology might need to be simplified). The activity statement as it is written leaves all this to the imagination, and emphasizes an activity rather then the concepts that should be learned through that activity.

(3) Have the correct science vocabulary and terminology been used?

Yes, except as noted in (1) above (in some of the standards, there are some problems with the use of the terms *hypothesis*, *theory*, and *kingdom*). However, there are certainly many scientific terms that students will need to learn that are not included in this document, so again, it is clearly not meant to be a comprehensive guide.

(4) Are the science process skill statements written at the appropriate grade level or course?

Yes, except for minor points noted above.

(5) Are the science concept/content statements grade-level appropriate?

For the most part the statements are grade-level appropriate at the high school level, although there is rarely any information about how the concepts should be taught for a given grade level. The lack of guidelines or explanations for teachers is more of a problem at the earliest grade levels. Young students can learn about the role of models in science, but they can't simply be told that "models are important for science," of course, which is one way that the statements could be interpreted. I can see that the guidelines could be used quite effectively by a teacher with an appropriate background in the sciences, but quite ineffectively by a teacher with no such background. If teachers don't have a background in science, the guidelines will offer little help. Therefore, one has to assume that competent teachers (who are trained at the appropriate grade level, and also have training in science fields) are teaching this material. Unfortunately, many of the teachers of this material (especially in the earlier grades) may not have the

appropriate background and training in the sciences to understand issues such the roles of investigation, inference, evaluation, testing, modeling, and theory in the sciences well enough to teach this material. All of these words are used differently (they have a more precise definition) in the sciences than in the casual sense they are used in everyday language. In particular, Grade 5 (b) (3) (a) is problematic: "analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information." Once again, this statement confuses or confounds scientific hypotheses and theories, and the distinction is unlikely to be clear to many Grade 5 teachers. I think students at this level can evaluate simple hypotheses and use data to distinguish among them. However, asking students in Grade 5 to analyze, review, and critique any modern scientific theory is absurd; how can any students in K-12 be expected to evaluate the enormous body of evidence that leads to current scientific consensus? I think this statement simply reflects a common misunderstanding of the word "theory" as it is used in science. Grade 5 (b) (3) (a) could be corrected: "evaluate example scientific hypotheses using scientific evidence and information." Although this is possible for very simple hypotheses and example data sets in Grade 5, even this simplified goal will require specialized training of teachers.

The TEKS for Grades 6-8 do not provide enough of a transition from the very basic science skills and concepts presented in K-5 to the more in-depth material presented in high school. Too much of the material seems repetitious with the earlier grades. In addition, there are some awkwardly worded statements, such as Grade 7 (b)(9)(A), which implies that life is known to exist on planets in our solar system other than Earth!

At the high school level, teachers with appropriate training in the various disciplines are more the norm, and they should be able to use these guidelines to develop grade-appropriate courses (except as noted elsewhere in this report).

(6) Do the science TEKS have Student Expectations (SEs) that are aligned with the knowledge and skills statements?

Yes, except as noted above.

(7) Are the Student Expectations (SEs) clear and specific?

I noted problems in various SEs in answering the questions above.

Other comments:

There are some grammatical or typographic errors throughout the documents, but I assumed that my review should focus on the major content, rather than typos. For

examples, see the wording of Science, Grade 5, (b) (14) (A), or Science Grade 6, (b) (10) (A).