

# Review of Proposed Texas Essential Knowledge and Skills for Science

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*(Note: In the recommendations below, proposed new language to be added to the TEKS is underlined; also, all recommended changes are listed together in an appendix at the end.)*

Because my primary fields of expertise are the history and philosophy of science, science pedagogy, biological and chemical evolution, and the earth sciences, most of my comments on the draft standards will focus on these areas.

## **1. The Definition of Science**

**A. Definition of Science Standard.** The draft definition of science standard that appears throughout the TEKS<sup>2</sup> is incomplete and insufficient. The main version of the standard states:

Science is a way of learning about the natural world. Students should know how science has built a vast body of changing and increasing knowledge described by physical, mathematical, and conceptual models, and also should know that science may not answer all questions.<sup>3</sup>

Stating that “science is a way of learning about the natural world” begs the question of *how* scientists learn about the natural world. The definition of science standard should do more to describe other key aspects of scientific inquiry. I would recommend drawing on language from the National Science Education Standards (NSES) in order to strengthen this standard. The NSES emphasizes that scientific “[i]nquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations.”<sup>4</sup> More specifically, scientific inquiry includes “the critical abilities of analyzing an argument by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models are best.”<sup>5</sup>

**Recommendation:** Throughout the TEKS,<sup>6</sup> add the following language to the definition of science standard wherever it appears: “Students should know that scientific ‘[i]nquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations’”; OR “Students should know that scientific inquiry requires ‘the critical abilities of analyzing an argument by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models are best.’”

**B. “Purported forces” Language.** Two versions of the definition of science standard add tendentious language about “purported forces that are outside of nature”:

Scientific explanations must be based on naturally occurring phenomena, and must be capable of testing by multiple independent researchers. If scientific explanations are based on purported forces that are outside of nature, scientists have no way of testing those explanations. Unless a proposed scientific explanation is framed in a way that some observational evidence could potentially refute it, that explanation cannot be subject to scientific testing.<sup>7</sup>

By using the word “purported” to describe forces outside of nature, this language seems to deny (or even ridicule) the idea that there are forces outside of nature. Surely, this is not an issue the TEKS for science should comment on, one way or another.

This version of the standard also raises vexing issues about the definition of science that professional historians and philosophers of science have not been able to resolve. The proposed language assumes that refutability (more commonly known as “falsifiability”) is an absolute criterion by which true scientific theories can be distinguished from non-scientific or pseudo-scientific theories. But the use of falsifiability as a criterion to distinguish science from non-science has been discredited by contemporary philosophers of science.<sup>8</sup> They note that scientific theories are often difficult to absolutely falsify in practice, and that it is not necessary to do so in order to test them. (Scientists can, for example, often provide evidence or reasons for preferring one theory over another without absolutely falsifying the less less-favored theory). As a result, treating falsifiability or refutability as a necessary condition of scientific status would have the effect of de-legitimizing many established scientific theories.<sup>9</sup>

**Recommendation:** Remove language from the TEKS about “purported forces... outside of nature” and the language equating testing with refutability. If there is a desire for students to learn about debates among philosophers of science about the definition of science, the following new language can be inserted: “Students should know about debates among scientists and philosophers of science about the definition of science.”

**C. Scientific Theories and New Evidence.** The treatment in the draft TEKS of the role played by new discoveries in science is misleading and inconsistent. High school Biology standard (b)(5) claims that:

Many theories in science are so well established that no new evidence is likely to alter them substantially; however, they are subject to continuing refinement as new areas of science emerge or as new technologies enable observations and experiments that were not possible previously (National Academy of Sciences, 2008, pp. 10-11).<sup>10</sup>

This language understates the important role played by new evidence and ideas in the history of science, and it fails to communicate the importance of scientific dissent in the progress of science. As many prominent scientists have pointed out, “[a]utomatically rejecting dissenting

views that challenge the conventional wisdom is a dangerous fallacy, for almost every generally accepted view was once deemed eccentric or heretical. Perpetuating the reign of a supposed scientific orthodoxy in this way ... is profoundly inimical to the search for truth.”<sup>11</sup> In addition, the wording of this standard in Biology is inconsistent with parallel wording found elsewhere in the standards. For example, the high school standards for Chemistry acknowledge that “many theories in science are well-established and highly reliable” but they also stress that “it is very likely that they will still be subject to changes as new areas of science and new technologies are developed.”<sup>12</sup> Unlike the Biology standards, the Chemistry standards offer no disclaimer that scientific theories “are so well established that no new evidence is likely to alter them substantially.” Indeed, this disclaimer is not found in the high school standards for Integrated Physics and Chemistry, Physics, Environmental Systems, Aquatic Science, Astronomy, Earth and Space Science, or Engineering Design. The Biology standard improperly singles out Biology as a scientific field where dissenting scientific viewpoints are unimportant.

High school Biology standard (b)(5) should be made consistent with the rest of the high school standards by removing the claim that many scientific theories “are so well established that no new evidence is likely to alter them substantially.”

The language used elsewhere in the high school standards about scientific theories being “well-established and highly reliable” should be retained, but refined. Science standards should “[e]ncourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.”<sup>13</sup> Thus, students need to know not only that many scientific theories are reliable, but that it is normal for scientific theories to be significantly revised based on new evidence and ideas. The history of science shows that the prevailing consensus among scientists may turn out be correct, but it may also turn out to be wrong, and so even prevailing scientific theories must be open to continuing evaluation, refinement, and refutation.<sup>14</sup>

**Recommendation:** Remove the disclaimer in high school Biology standard (b)(5) stating that “[m]any theories in science are so well established that no new evidence is likely to alter them substantially” and make the standard consistent with the language in the rest of the high school standards.

**Recommendation:** Add the following language to the relevant standards<sup>15</sup> in section (b) of the TEKS for grades 9-12: “The history of science shows that the prevailing consensus among scientists may turn out be correct, but it may also turn out to be incorrect, and so even prevailing scientific theories should be open to continuing refinement, evaluation, and refutation.”

## **2. Critical Thinking and Scientific Inquiry**

**A. Critical Thinking Standard.** Critical thinking, including the evaluation of competing interpretations of evidence, lies at the heart of scientific inquiry; and so the way in which the

TEKS seek to implement critical thinking skills across the curriculum is extremely important. Unfortunately, in the draft TEKS the main standard focused on critical thinking is inconsistent across grades and disciplines. One version of the standard says that students should

analyze and evaluate scientific explanations using empirical evidence, logical reasoning, and experimental and observational testing.<sup>16</sup>

A second version of the standard asks students to

analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information.<sup>17</sup>

The first version of the standard clearly specifies the use of empirical evidence, logical reasoning, and experimental and observational testing in scientific analysis and review. But the first version does not provide adequate guidance to teachers as to what analysis and review should mean in practice. The second version of the standard (drawn from the existing TEKS) is much stronger on this point, because it makes clear that the evaluation of scientific explanations should include an examination of the scientific strengths and weaknesses of those explanations.

Philosophers of science such as Marcello Pera have made it clear that scientists advance their understanding by weighing competing scientific hypotheses and debating competing interpretations of the scientific evidence.<sup>18</sup> Other scientists and philosophers of science have made clear that scientists often engage in a comparative evaluation procedure that involves assessing the explanatory power of competing theories.<sup>19</sup> Thus, science education that does not encourage students to evaluate competing scientific arguments is not teaching students about the way science actually operates. It is not modeling for students the true nature of scientific inquiry. Simply presenting students with current scientific conclusions by rote without having them examine the reasoning and assumptions that underlie those conclusions disserves students by presenting them with a false view of the way scientists work. Science education needs to incorporate more comparative analysis of the evidence, not less. As noted rhetorician of science John Angus Campbell has pointed out:

For a modern scientist, early education in comparative argument and persuasive communication forms a core of foundational skills indispensable for future achievement—irrespective of the content of tomorrow’s theories. A contemporary scientist must know not only how to put a hypothesis forward but how to put it across. A scientist gets grants. Having gotten them and done the experiments, the researcher must interpret the results, show what has been discovered, draw out its implications, and show why funding for more experiments, or experiments of a new kind, is now necessary. In addition, the scientist must defend his or her work against possible counterfindings of other independent peers working in the same field,

sharing the same love of truth and competing for the same research dollars, promotions, prizes, and recognition...<sup>20</sup>

Campbell adds that the same training “is no less important for tomorrow’s citizens,” noting the “the stressful necessity that modern medicine routinely places on laypeople to challenge expert advice and seek a second or third opinion” in order to determine their best treatment option.<sup>21</sup>

By insisting that students examine the “strengths and weaknesses” of scientific explanations, the second version of the critical thinking standard does a better job of encouraging the comparative evaluation of scientific arguments on which the progress of science depends. The need to train students to investigate the “strengths and weaknesses” of scientific explanations has been clearly recognized by the National Research Council (NRC):

At each of the steps involved in inquiry, students and teachers ought to ask “what counts?” What data do we keep? What data do we discard? What patterns exist in the data? Are these patterns appropriate for this inquiry? What explanations account for the patterns? Is one explanation better than another? In justifying their decisions, students ought to draw on evidence and analytical tools to derive a scientific claim. In turn, students should be able to assess both the strengths and weaknesses of their claims.”<sup>22</sup>

The NRC similarly stresses that “[t]hroughout the process of inquiry” students should “constantly evaluate and reevaluate the nature and strength of evidence and share and then critique their explanations and those of others.”<sup>23</sup>

If there is a weak point in the current “strengths and weaknesses” formulation, it is the lack of definition for the phrase “scientific evidence and information.” To fix this, I would replace the phrase with the wording from the latter half of version one of the standard: “empirical evidence, logical reasoning, experimental and/or observational testing.”

I recognize there has been a campaign to strip the “strengths and weaknesses” language from the new version of the TEKS, *even though that language has been included in the Texas science standards for many years*. This campaign has more to do with ideology than good pedagogy, as can be seen from the website of one of the groups leading the effort to eliminate the “strengths and weaknesses” language. The group issued a statement (signed by two other expert reviewers of the draft TEKS) urging the State Board of Education to disapprove of any science standards containing the “strengths and weaknesses” terminology because the language allegedly has been used by “politicians... to introduce supernatural explanations into science courses.”<sup>24</sup> The statement provides no documentation for this claim, and the “strengths and weaknesses” language in the TEKS explicitly authorizes only analysis and critiques of scientific theories currently described in the TEKS. It does not authorize any discussion of supernatural explanations. Nor is there any serious proposal to change that. Thus, this charge is without foundation in fact.

As an historian of science, I am all too familiar with the rhetorical strategy being employed here. During the past century, it became common to invoke “religion” as a bogeyman in order to suppress legitimate scientific dissent, playing on fears that religion is somehow “anti-science.”<sup>25</sup> In the nineteenth century, polemicists such as John William Draper and Andrew Dickson White tried to rewrite the history of science as one long war between science and religion.<sup>26</sup> Turning to more recent events, during the Texas science textbook adoption process in 2003, certain activists alleged that efforts to correct factual errors in textbooks and introduce discussions of scientific criticisms of modern evolutionary theory constituted the promotion of “religion.” The claim was false. The recommendations made at the time were based on information from mainstream peer-reviewed science sources.<sup>27</sup>

The goal of opponents of the “strengths and weaknesses” language seems to be the singling out of Darwinian evolution to shield it from the normal process of scientific inquiry and scrutiny. The irony is that Darwin himself would have repudiated such an effort. He formulated his theory as “one long argument.” In the process of making his case, he carefully assessed the explanatory power of his theory and compared it to that of rival hypotheses. If we wish to teach Darwin’s theory as he himself presented it, we need to acquaint students with the method of multiple competing hypotheses. We also need to model this method of scientific reasoning in the way we present scientific facts and arguments. Indeed, Darwin himself acknowledged that “a fair result can be obtained only by fully stating and balancing the facts and arguments on both sides of each question.”<sup>28</sup>

**Recommendation:** Create a uniform version of the critical thinking standard that applies across grades and courses,<sup>29</sup> modifying the “strengths and weaknesses” language as follows: “analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using empirical evidence, logical reasoning, experimental and/or observational testing.”

(Note: Some science uses experimental methods of testing; other sciences, in particular historical sciences, use observational methods of testing that do not necessarily involve experiments under controlled laboratory conditions.<sup>30</sup> Thus, the phrase “experimental **and** observational testing” should be changed to “experimental **and/or** observational testing.”)

**B. Critical Thinking Throughout the Curriculum.** It is not enough to have a general standard calling for the examination of the strengths and weaknesses of scientific explanations. The critical thinking approach needs to be applied to topics and issues throughout the curriculum. Fortunately, this has been done already in a number of areas of the TEKS. For example, in the high school standards for Integrated Physics and Chemistry, students are asked to

critique the advantages and disadvantages of various energy sources and their impact on society and the environment.<sup>31</sup>

Similarly, in the standards for Environmental Systems, students are asked to

research the advantages and disadvantages of ‘going green’ such as organic gardening/farming, methods of pest control, hydroponics, xeriscaping, energy efficient homes/appliances and hybrid cars.<sup>32</sup>

But in other fields—most notably, the high school standards relating to biological evolution—there seems to have been little attempt to incorporate critical thinking. Below I offer suggestions for how to strengthen the critical thinking component of various parts of the standards (except for high school biology, which I will treat in section 4 of this review). In addition to my recommendations here, I encourage a thorough review of the standards to determine other places where language dealing with critical analysis can be strengthened.

**Recommendation:** Modify high school Environmental Systems standard (c)(9)(B) to read: “analyze the strengths and weaknesses of scientific hypotheses about the effect of pollution on global warming, glacial/ice cap melting, greenhouse effect, ozone layer, and aquatic viability.”

**Recommendation:** Modify high school Environmental Systems standard (c)(9)(C) to read: “analyze the strengths and weaknesses of scientific hypotheses about the effect of recreational activities such as, hunting, fishing, ecotourism, all terrain vehicles, and small personal water craft on the environment.”

**Recommendation:** Modify high school Environmental Systems standard (c)(9)(F) to read: “analyze the strengths and weaknesses of local, state and national legislation and international treaties/protocols including, Texas automobile emissions regulations, National Park Service Act, and Kyoto Protocol.”

**Recommendation:** Modify high school Aquatic Science standard (c)(12)(D) to read: “analyze the strengths and weaknesses of scientific hypotheses about how human activities such as fishing, transportation, dams, and recreation have influenced aquatic environments.”

**Recommendation:** Modify high school Aquatic Science standard (c)(12)(E) to read: “understand the arguments about positive and negative impacts of various laws and policies (such as The Endangered Species Act, right of capture laws, or Clean Water Act) on aquatic systems and society.”

**Recommendation:** Modify high school Astronomy standard (c)(13)(C) to read: “analyze the strengths and weaknesses of scientific hypotheses about the fate of the universe, including open and closed universe models, dark matter, and dark energy.”

**Recommendation:** Modify high school Earth and Space Science standard (c)(4)(A) to read: “evaluate the strengths and weaknesses of the arguments for the Big Bang model that reveals an expanding universe originating from an initial singularity about 14 billion years ago.”

**Recommendation:** Modify high school Earth and Space Science standard (c)(6)(A) to read: “analyze the strengths and weaknesses of the arguments for the evolution of Earth’s atmosphere over time from the original protoplanet hydrogen-helium atmosphere, the carbon dioxide-water vapor-methane atmosphere, and the current nitrogen-oxygen atmosphere.”

**Recommendation:** Modify high school Earth and Space Science standard (c)(6)(B) to read: “evaluate the evidence for the hypothesis that volcanic outgassing and the impact of water-bearing comets have played a major role in creating Earth’s atmosphere and hydrosphere.”

**Recommendation:** Modify high school Earth and Space Science standard (c)(6)(D) to read: “evaluate the evidence for the hypothesis that the Earth’s cooling led to tectonic activity, resulting in continents and ocean basins.”

**Recommendation:** Modify high school Earth and Space Science standard (c)(8)(B) to read: “evaluate a variety of fossil types, significant fossil deposits and proposed transitional fossils and fossil lineages, and assess the arguments for and against universal common descent in light of this fossil evidence.”

**Recommendation:** Modify high school Earth and Space Science standard (c)(13)(D) to read: “analyze the strengths and weaknesses of hypotheses about the effects of the following factors and mechanisms on changes in the Earth’s climate: atmospheric carbon dioxide concentration, major volcanic eruptions, changes in solar luminance, giant meteorite impacts, and human activities.”

### **3. History and Social Impact of Science**

The relationship between science and culture is multi-faceted. On the one hand, cultural beliefs and attitudes have shaped the development of modern science; on the other hand, the practice of modern science has influenced and continues to influence society and culture. The current draft of the standards does a poor job in explaining exactly what students should know in both areas.

***A. The Impact of Culture on the Development of Science.*** Modern science did not develop in a vacuum, yet the draft standards do not clearly require students to learn about the cultural factors that influenced the development of modern science. There are a few standards stating generally that students should know about the history of a discipline, but these standards for the most part provide no guidance on what parts of the “history” of the discipline students need to know

about.<sup>33</sup> The major exception is the standard for high school astronomy, which does provide an excellent list of historical topics to be studied.<sup>34</sup>

The overall lack of specificity relating to the history of science stands in marked contrast to the detailed enumeration of scientific concepts, theories, and information that one finds throughout the rest of the standards. At a minimum, language needs to be added throughout the TEKS requiring students to learn about the impact of culture on the rise of science. One cannot fully appreciate both the strengths and the limits of science as a way of knowing without understanding the cultural assumptions and attitudes that helped to nourish it. Over the past century there has been a wealth of scholarship examining the philosophical, historical, economic, religious, and other factors leading to the rise of modern science. If students do not learn about these factors, then they will be left with a shallow and misleading understanding of how science develops. In particular, they will fail to appreciate the way in which science often builds upon knowledge and intuitions gleaned from other fields and disciplines—e.g., the way Darwin drew upon the work of political economist Thomas Malthus<sup>35</sup> in the development of his theory of natural selection; or the way in which certain religious beliefs supported the development of modern natural science.<sup>36</sup>

**Recommendation:** Modify the history of science standard that typically appears in section (c)(3) of each set of TEKS to require students to learn about the cultural (political, economic, intellectual, religious) factors that influenced the development of modern science.

***B. The Impact of Science on Culture and Society.*** There are standards in the draft TEKS dealing with the impact of science on society, but they are inconsistent and vague, and most provide little guidance to teachers about what students are expected to learn. In grades 5-8, the standards dealing with the impact of science on society at least include concrete examples of scientists who should be studied. However, in grades 9-12, the main standards on the impact of science in society are utterly vague. The typical wording (which usually appears as standard (c)(3)(C)) asks students to “evaluate the impact of research on scientific thought, society, and the environment.”<sup>37</sup> But what does “evaluate” mean in this context, and what are the kinds of impacts that should be evaluated? The standard does not give any guidance. I would suggest refining the language to ensure that students understand that science can have both positive and negative impacts on society, and providing examples of such impacts (preferably that are discipline-specific). Studying both positive and negative impacts of scientific research is another way of incorporating the critical thinking approach.

**Recommendation:** Revise the main standard on the impact of science on society in each high school course (typically standard (c)(3)(C)) to require students to learn about both the positive and negative social impacts of science in the discipline under study. Examples of key positive and negative impacts also should be provided.

#### **4. High School Biology**

**A. Social Impact of Science.** As noted in section 3B, the TEKS need to be strengthened in their coverage of the social impact of science, especially in high school. Ideally, the TEKS should give discipline-specific examples of the positive and negative impacts of science that students should learn about. In the area of biology, positive examples of the social impact of science might include the germ theory of disease and the development of antibiotics, both of which made significant contributions to public health. Negative examples might include the eugenics movement, the Tuskegee syphilis experiment, and theories of scientific racism. Simply cheerleading for the benefits of science to society is not appropriate; neither is simply highlighting the abuses of science in history. Students must gain an accurate understanding of both the positive and negative impacts science can have on society.

**Recommendation:** Modify high school Biology standard (c)(3)(C) to read: “evaluate the positive and negative impacts of biological research on society by studying examples from history including the germ theory of disease, the development of antibiotics, eugenics, the Tuskegee syphilis experiment, and theories of scientific racism.”

**B. Definition of Evolution.** The high school Biology standards do not contain an adequate definition of the term evolution. Standard (c)(7) describes evolution as “an explanation for the diversity of life,” but that description is woefully incomplete. If biological evolution is as central to modern biology as many of its defenders insist, the science standards (at a minimum) should require students to understand clearly what the term evolution means. There are actually multiple meanings of evolution used in the scientific and popular literature.<sup>38</sup> Students should be able to distinguish between these different meanings, including change over time, universal common ancestry, and natural selection acting on random variation. Students also need to understand the important ways evolutionary biology differs from some other scientific fields. As Harvard evolutionary biologist Ernst Mayr pointed out:

Evolutionary biology, in contrast with physics and chemistry, is a historical science—the evolutionist attempts to explain events and processes that have already taken place. Laws and experiments are inappropriate techniques for the explication of such events and processes. Instead one constructs a historical narrative, consisting of a tentative reconstruction of the particular scenario that led to the events one is trying to explain.<sup>39</sup>

Students need to know that evolution is primarily an historical science and understand the key characteristics of the historical sciences.

**Recommendation:** Insert the following additional standard under section (c)(7) of the high school Biology standards: “know and distinguish between the different meanings of the term evolution, including change over time, universal common

ancestry, and natural selection acting on random variations; and understand that evolutionary biology is primarily an historical science.”

**C. Common Ancestry.** Biology standard (c)(7)(A) asks students to

identify how evidence of common ancestry among groups is provided by the fossil record, biogeography, and homologies including anatomical, molecular, physiological, behavioral and developmental.<sup>40</sup>

This standard appropriately calls for students to learn about the major types of evidence used by scientists to support the idea of universal common ancestry. However, the draft language does not require students to know enough about the scientific arguments for and against the hypothesis of universal common ancestry. Simply having students identify evidence supporting common ancestry without having them analyze any conflicting scientific evidence and arguments is promoting learning by rote rather than scientific inquiry; it also presents an inaccurate view of the current state of this aspect of modern Darwinian theory. A better approach would be to ask students to examine the strengths and weaknesses of the scientific arguments for and against universal common ancestry.

For those who insist that there are no “weaknesses” in the traditional case for universal common ancestry, let me cite a few examples:

(1) The fossil record shows a pattern of explosions of new life-forms that contradicts the predictions and expectations of universal common descent and suggests the possibility of a discontinuous (polyphyletic) view of the history of life, rather than a continuous (monophyletic) view of the history of life. This is seen most strikingly in the Cambrian explosion, the geologically sudden appearance of numerous new animal forms (and their distinctive body plans) 530 million years ago.<sup>41</sup> As one college-level textbook acknowledges, “[m]ost of the animal phyla that are represented in the fossil record first appear, ‘fully formed,’ in the Cambrian ... The fossil record is therefore of no help with respect to the origin and early diversification of the various animal phyla.”<sup>42</sup> But the Cambrian explosion is only one of various “explosions” in the fossil record. Paleontologists have observed explosions of fish species,<sup>43</sup> a plant explosion,<sup>44</sup> a bird explosion,<sup>45</sup> and even a mammal explosion.<sup>46</sup> Geologically abrupt explosions of mass biological diversity seem to be the rule for the fossil record. Evolutionary transitions plausibly documented by fossils seem to be the rare exception. Paleontologist Stephen Jay Gould observed that “[t]he absence of fossil evidence for intermediary stages between major transitions in organic design, indeed our inability, even in our imagination, to construct functional intermediates in many cases, has been a persistent and nagging problem for gradualistic accounts of evolution.”<sup>47</sup>

(2) Proponents of neo-Darwinian evolution hold that genetic similarities between species almost always indicate inheritance from a common ancestor. But there are numerous cases where conflicts exist between different types of gene-based evolutionary trees, thus challenging the

very evidence and methodology used to infer common descent from “molecular homologies.” The biotechnology revolution has led to the discovery that similarities even among genes are not always reliable indicators of the degree of relatedness. The basic problem is that evolutionary trees based on one protein commonly differ from a family tree based on a different protein.<sup>48</sup> Some leading biologists have concluded that the molecular evidence is inconsistent with the notion that the basic domains of life (e.g., bacteria, plants and animals) evolved from a single common ancestor. As W. Ford Doolittle explains, “[m]olecular phylogenists will have failed to find the ‘true tree,’ not because their methods are inadequate or because they have chosen the wrong genes, but because the history of life cannot properly be represented as a tree,”<sup>49</sup> elsewhere observing that “there would never have been a single cell that could be called the last universal common ancestor.”<sup>50</sup> Doolittle believes that this data can be explained by horizontal gene-swapping among microorganisms at the base of the tree, but Carl Woese, an eminent molecular systematist, found that the problem is not just with the base of the tree: “[I]ncongruities can be seen everywhere in the universal tree, from its root to the major branchings within and among the various taxa to the makeup of the primary groupings themselves.”<sup>51</sup>

(3) In a textbook that I have recently co-authored, my colleagues and I show that there are other classes of evidence for and against the hypothesis of universal common descent.<sup>52</sup>

**Recommendation:** Modify Biology standard (c)(7)(A) to read: “analyze, review, and critique the strengths and weaknesses of the arguments for universal common ancestry including those based upon the fossil record, biogeography, molecular and anatomical homology, and developmental biology.”

**D. Natural Selection and the Mechanisms of Evolution.** There are several standards emphasizing natural selection and related mechanisms of evolution. Students are asked to

recognize that natural selection produces change in populations, not individuals.<sup>53</sup>

describe the elements of natural selection including inherited variation, the potential of a population to produce more offspring than can survive, and a finite supply of environmental resources resulting in differential reproductive success.<sup>54</sup>

recognize the significance of natural selection to adaptation, and to the diversity of species.<sup>55</sup>

analyze the results of other evolutionary mechanisms including genetic drift, gene flow, mutation, and recombination.<sup>56</sup>

Because natural selection and random mutation form the core mechanism of modern evolutionary theory (sometimes known as “neo-Darwinism”), it is critically important that students learn about both topics in depth—including being exposed to competing scientific

arguments and evidence about their strengths and weaknesses as scientific explanations. There is strong empirical evidence that the selection-mutation mechanism can produce certain kinds of evolutionary changes in populations, and students need to fully understand this evidence. However, as the result of a growing body of evidence, many scientists now question the ability of selection and mutation to produce major evolutionary changes. Students need to learn about this evidence as well. Unfortunately, the draft standards for high school Biology do not ensure that students will do this. As a result, students may receive an inaccurate presentation of current science.

Over the last two decades, a host of scientific articles and books have questioned the efficacy of selection and mutation as a mechanism for generating morphological novelty, as even a brief literature survey will establish. Thomson (1992) expressed doubt that large-scale morphological changes could accumulate via minor phenotypic changes at the population genetic level.<sup>57</sup> Miklos (1993) argued that neo-Darwinism fails to provide a mechanism that can produce large-scale innovations in form and complexity.<sup>58</sup> National Academy of Sciences biologist Lynn Margulis (2003) has argued that “new mutations don’t create new species; they create offspring that are impaired.”<sup>59</sup> Margulis explained that mutations do not provide any useful raw materials because they tend to destroy function, introducing sickness and death:

We agree that very few potential offspring ever survive to reproduce and that populations do change through time, and that therefore natural selection is of critical importance to the evolutionary process. But this Darwinian claim to explain all of evolution is a popular half-truth whose lack of explicative power is compensated for only by the religious ferocity of its rhetoric. Although random mutations influenced the course of evolution, their influence was mainly by loss, alteration, and refinement. One mutation confers resistance to malaria but also makes happy blood cells into the deficient oxygen carriers of sickle cell anemics. Another converts a gorgeous newborn into a cystic fibrosis patient or a victim of early onset diabetes. One mutation causes a flighty red-eyed fruit fly to fail to take wing. Never, however, did that one mutation make a wing, a fruit, a woody stem, or a claw appear. Mutations, in summary, tend to induce sickness, death, or deficiencies. No evidence in the vast literature of heredity changes shows unambiguous evidence that random mutation itself, even with geographical isolation of populations, leads to speciation.<sup>60</sup>

Gilbert et al. (1996) attempted to develop a new theory of evolutionary mechanisms to supplement classical neo-Darwinism, which, they argued, could not adequately explain macroevolution. Though Gilbert attempted to solve the problem of the origin of form by proposing a greater role for developmental genetics within an otherwise neo-Darwinian framework,<sup>61</sup> numerous recent authors have continued to raise questions about the adequacy of that framework itself or about the problem of the origination of form generally.<sup>62</sup>

Many scientists and mathematicians have questioned the ability of mutation and selection to generate information in the form of novel genes and proteins. Some have questioned whether mutation and selection would have a reasonable chance of locating new islands of function—representing fundamentally new genes or proteins—within the time available.<sup>63</sup> Some have also argued that alterations in sequencing would likely result in loss of protein function before fundamentally new function could arise.<sup>64</sup> Recent experiments in molecular biology have accentuated these concerns.<sup>65</sup>

The problems with the neo-Darwinian mechanism of selection-mutation run deeper still. In order to explain the origin of new animals, one must account not only for new proteins and cell types, but also for the origin of new body plans. Within the past decade, developmental biology has dramatically advanced our understanding of how body plans are built during ontogeny. In the process, it has also uncovered a profound difficulty for neo-Darwinism. Significant morphological change in organisms requires attention to timing. Mutations in genes that are expressed late in the development of an organism will not affect the body plan. Mutations expressed early in development, however, could conceivably produce significant morphological change.<sup>66</sup> Thus, events expressed early in the development of organisms have the only realistic chance of producing large-scale macroevolutionary change.<sup>67</sup> Yet recent studies in developmental biology make clear that mutations expressed early in development typically have deleterious effects.<sup>68</sup> This problem has led to what geneticist John McDonald has called “a great Darwinian paradox.”<sup>69</sup> Mutations that cannot produce major evolutionary changes (namely, viable genetic mutations in DNA expressed late in development) do occur, but mutations that could produce major evolutionary changes (namely, beneficial body plan mutations expressed early in development) apparently do not occur.

Developmental biology has raised another formidable hurdle for the selection-mutation mechanism. Embryological evidence has long shown that DNA does not wholly determine morphological form, suggesting that mutations in DNA alone cannot account for the morphological changes required to build a new body plan.<sup>70</sup> DNA helps direct protein synthesis. It also helps to regulate the timing and expression of the synthesis of various proteins within cells. Yet, DNA alone does not determine how individual proteins assemble themselves into larger systems of proteins; still less does it solely determine how cell types, tissue types, and organs arrange themselves into body plans.<sup>71</sup> Instead, other factors—such as the three-dimensional structure and organization of the cell membrane and cytoskeleton and the spatial architecture of the fertilized egg—play important roles in determining body plan formation during embryogenesis.<sup>72</sup>

Simply for the sake of accuracy, the TEKS Biology standards need to ensure that students learn about the scientific debates over the creative power and limits of the selection-mutation mechanism. But beyond the issue of accuracy, these debates over natural selection and mutation provide a superb opportunity for students to apply the critical thinking skills called for in the rest of the TEKS.

**Recommendation:** Modify high school Biology standard (c)(7)(D) to read: “analyze the strengths and weaknesses of arguments for the ability of natural selection to produce new adaptations and a diversity of species, as well as higher taxonomic groups and new body plans.”

**Recommendation:** Modify high school Biology standard (c)(7)(E) to read: “analyze the strengths and weaknesses of arguments for the ability of other evolutionary mechanisms including genetic drift, gene flow, mutation, and recombination to produce significant evolutionary change”

**E. Universality of the Genetic Code.** Standard (c)(6)(B) asks students to “recognize that the genetic code is common to all organisms.”<sup>73</sup> This indicator is not entirely accurate, for there are some organisms that use a slightly different genetic code from the standard code, and in fact suggestions have been made that the existence of various codes contradict the expectations of the theory of universal common ancestry.<sup>74</sup> As one authority wrote in *Current Biology*, “Once thought universal, the specific relationships between amino acids and codons that are collectively known as the genetic code are now proving to be variable in many taxa. While this realization has been disappointing to some—the genetic code was often hailed as the ultimate evolutionary anchor in that its universality was perhaps the indisputable piece of evidence that all life shared a common ancestor at some point—it has also opened up a rich field of evolutionary analysis by forcing us to consider what sequence of molecular events in a cell could possibly allow for codon reassignment.”<sup>75</sup> If students are taught that “the genetic code is common to all organisms,” then they will be presented with an erroneous picture of the evidence.

**Recommendation:** Modify high school Biology standard (c)(6)(B) to read: “recognize that the genetic code is similar in most organisms but that there are variations in the genetic code. Analyze whether this evidence supports or challenges the theory of universal common ancestry.”

**F. Gene Regulation.** Standard (c)(6)(D) asks students to “recognize that gene expression is a regulated process.”<sup>76</sup> This standard should be made more specific to incorporate recent discoveries that non-coding DNA regulates gene expression.<sup>77</sup>

**Recommendation:** Modify high school Biology standard (c)(6)(D) to read: “recognize that the genome contains both protein-coding and non-protein-coding DNA and that gene expression is a process regulated largely by non-coding DNA.”

**G. Origin of Life.** There is no Biology standard dealing with the origin of the first self-replicating biological organisms, although such a standard appears in the elective high school course on Earth and Space Science.<sup>78</sup> The origin of life is obviously a foundational issue in biology, which is why it is covered (although poorly) in most biology textbooks. This is a major omission in the standards that needs to be rectified.

**Recommendation:** Add a high school Biology standard about the origin of life: “analyze, review, and critique the strengths and weaknesses of various hypotheses about the origin of life, including those involving a pre-biotic soup. Specifically, evaluate the ability of these hypotheses to explain the origin of: organic monomers under primitive Earth conditions; the origin of complex biopolymers such as proteins, RNA, or DNA; the origin of sequence-specific information in proteins, RNA and DNA; and the origin of a primitive self-replicating life-form.”

## **5. High School Earth and Space Science**

**A. *Origin of Life Standard.*** Standard (c)(8)(A) asks students to

analyze prominent scientific hypotheses for the origin of life by abiotic chemical processes, such as the transport of organic chemicals to Earth by comets, low-energy clay mineral replication, primitive Earth replication experiments, and the significance of primitive extremophilic archaeans.<sup>79</sup>

The inclusion of a standard on the origin of life is to be commended, although the draft wording has problems. First, the wording does not require students to analyze the strengths and weaknesses of origin of life hypotheses. Considering the vigorous debate among scientists over competing origin of life scenarios, the standard definitely should require the application of critical thinking skills. This is another excellent opportunity to involve students in genuine scientific inquiry by allowing them to compare, contrast, and evaluate competing hypotheses and arguments.

Second, the draft standard asks students to learn about mechanisms of obtaining prebiotic organic chemicals on the early Earth, highlighting the hypothesis that organic chemicals might have been brought to earth by comets. Why the focus on comets? Comet delivery of organic molecules has never been the dominant hypothesis of prebiotic synthesis, and in fact there are extremely good reasons to expect that biological molecules on comets would not survive the impact events when comets hit the earth. As Edward Anders wrote in *Nature*, “organic matter cannot survive the extremely high temperatures ( $>10^4$  K) reached on impact, which atomize the projectile and break all chemical bonds.”<sup>80</sup> The standard ignores the predominant view of prebiotic synthesis, which is that atmospheric conditions on the early Earth produced a worldwide sea of “primordial soup.” This dominant view also faces a myriad of problems, because it is now known that Earth’s early atmosphere was composed primarily of carbon dioxide (CO<sub>2</sub>) and nitrogen (N<sub>2</sub>) which do not lead to the production of a such a soup.<sup>81</sup> But students still need to know about this dominant view.

Finally, the standard does not make it clear that prebiotic synthesis represents just one early step in the origin of life. In his book *Information and the Origin of Life*, origin of life theorist Bernd-Olaf Kuppers stated that, “The problem of the origin of life is clearly basically equivalent to the

problem of the origin of biological information.”<sup>82</sup> But the draft standard ignores this significant problem, for which there is currently no known solution.<sup>83</sup>

**Recommendation:** Substitute the following wording for high school Earth and Space Science standard (c)(8)(A) about the origin of life: “analyze, review, and critique the strengths and weaknesses of various hypotheses about the origin of life, including those involving a pre-biotic soup, hydrothermal steam vents, and the transport of organic chemicals to Earth by comets. Specifically, evaluate the ability of these hypotheses to explain the origin of: organic monomers under primitive Earth conditions; the origin of complex biopolymers such as proteins, RNA, or DNA; the origin of sequence-specific information in proteins, RNA and DNA; the origin of the modern genetic code system; the origin of a primitive self-replicating life-form; and the origin of a minimally complex free-living cell.”

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<sup>2</sup> The definition of science standard discussed here appears in many places in the TEKS, but its usage is inconsistent. The TEKS for grades 6-8 utilize different wording that appears as standard (a)(3)(A)(iii). The TEKS for grade 4 do not appear to contain a clear definition of science. Standard (a)(6) in Grade 5 seems to be a modified version of the main standard, and is not framed as a definition of science. It would be good to standardize the definition of science as it appears across grade levels and courses in the TEKS.

<sup>3</sup> Integrated Physics and Chemistry, standard (b)(2), TEKS, Grades 9-12. Also see Biology, standard (b)(2), TEKS, Grades 9-12; Chemistry, standard (b)(2), TEKS, Grades 9-12; Physics, standard (b)(2), TEKS, Grades 9-12; Environmental Systems, standard (b)(2), TEKS, Grades 9-12; Aquatic Science, standard (b)(2), TEKS, Grades 9-12; Astronomy, standard (b)(2), TEKS, Grades 9-12; Kindergarten, standard (a)(3), TEKS, Grades K-5; Grade 1, standard (a)(3), TEKS, Grades K-5; Grade 2, standard (a)(3), TEKS, Grades K-5; Grade 3, standard (a)(4), TEKS, Grades K-5.

<sup>4</sup> National Research Council, *National Science Education Standards* (National Academy Press, 1996), p. 23.

<sup>5</sup> *Ibid.*, p. 175

<sup>6</sup> Add to Integrated Physics and Chemistry, standard (b)(2), TEKS, Grades 9-12; Biology, standard (b)(2), TEKS, Grades 9-12; Chemistry, standard (b)(2), TEKS, Grades 9-12; Physics, standard (b)(2), TEKS, Grades 9-12; Environmental Systems, standard (b)(2), TEKS, Grades 9-12; Aquatic Science, standard (b)(2), TEKS, Grades 9-12; Astronomy, standard (b)(2), TEKS, Grades 9-12; Kindergarten, standard (a)(3), TEKS, Grades K-5; Grade 1, standard (a)(3), TEKS, Grades K-5; Grade 2, standard (a)(3), TEKS, Grades K-5; Grade 3, standard (a)(4), TEKS, Grades K-5. Also add to the TEKS for grades 4-8 if the definition of science in those grades is made consistent with the definition offered elsewhere in the TEKS.

<sup>7</sup> Earth and Space Science, standard (b)(5), TEKS, Grades 9-12; also see Biology, standard (b)(5), TEKS, Grades 9-12.

<sup>8</sup> Imre Lakatos, “Falsification and the Methodology of Scientific Research Programmes,” in Imre Lakatos & Alan Musgrave, editors, *Criticism and the Growth of Knowledge* (Cambridge University Press, 1970), pp. 189-95.

<sup>9</sup> See section on “The Demise of Demarcation Arguments” in David DeWolf, Stephen C. Meyer, and Mark E. DeForrest, “Teaching the Controversy: Is It Science, Religion, or Speech?” in Campbell and Meyer, editors, *Darwinism, Design, and Public Education*, pp. 75-79.

<sup>10</sup> Biology, standard (b)(5), TEKS, Grades 9-12.

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<sup>11</sup> Brief Amici Curiae Physicians, Scientists, and Historians of Science in Support of Petitioners, *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 509 U.S. 579 (1993).

<sup>12</sup> Chemistry, standard (b)(2), TEKS, Grades 9-12.

<sup>13</sup> *National Science Education Standards*, Teaching Standard B, p. 43.

<sup>14</sup> Thomas Kuhn, *The Structure of Scientific Revolutions* (University of Chicago Press, 1962); Brief Amici Curiae Physicians, Scientists, and Historians of Science in Support of Petitioners, *Daubert v. Merrell Dow Pharmaceuticals, Inc.*

<sup>15</sup> Integrated Physics and Chemistry, standard (b)(2) or (b)(4), TEKS, Grades 9-12; Biology, standard (b)(5), TEKS, Grades 9-12; Chemistry, standard (b)(2), TEKS, Grades 9-12; Physics, standard (b)(2), TEKS, Grades 9-12; Environmental Systems, standard (b)(2) or (b)(5), TEKS, Grades 9-12; Aquatic Science, standard (b)(2) or (b)(4) or (b)(5), TEKS, Grades 9-12; Astronomy, standard (b)(2) or (b)(4), TEKS, Grades 9-12; Earth and Space Science, standard (b)(7), TEKS, Grades 9-12.

<sup>16</sup> Integrated Physics and Chemistry, standard (c)(3)(A), TEKS, Grades 9-12; Biology, standard (c)(3)(A), TEKS, Grades 9-12; Physics, standard (c)(3)(A), TEKS, Grades 9-12; Environmental Systems, standard (c)(3)(A), TEKS, Grades 9-12; Aquatic Science, standard (c)(3)(A), TEKS, Grades 9-12; Earth and Space Science, standard (c)(3)(A), TEKS, Grades 9-12. A slightly different version is contained in the TEKS for Grades 6-8: “review and analyze scientific explanations y using student-generated empirical evidence, logical reasoning, and observational and experimental testing.” Grade 6, standard (b)(3)(A), TEKS, Grades 6-8; Grade 7, standard (b)(3)(A), TEKS, Grades 6-8; Grade 8, standard (b)(3)(A), TEKS, Grades 6-8.

<sup>17</sup> Fourth Grade, standard (b)(3)(A), TEKS, Grades K-5; Chemistry, standard (c)(3)(A), TEKS, Grades 9-12; Astronomy, standard (c)(3)(A), TEKS, Grades 9-12.

<sup>18</sup> Marcello Pera, *The Discourses of Science*, trans. Clarissa Botsford (University of Chicago Press, 1994); Marcello Pera and William R. Shea, *Persuading Science: The Art of Scientific Rhetoric* (Science History Publications, 1991).

<sup>19</sup> Peter Lipton, *Inference to the Best Explanation* (Routledge, 1991); Thomas C. Chamberlain, “The Method of Multiple Working Hypotheses,” *Science* (old series) 15:92-96 (1890); reprinted in *Science* 148:754-759 (1965).

<sup>20</sup> John Angus Campbell, “Why Are We Still Debating Darwinism?” in John Angus Campbell and Stephen C. Meyer, editors, *Darwinism, Design, and Public Education* (Michigan State University Press, 2003), p. xxviii.

<sup>21</sup> *Ibid.*

<sup>22</sup> National Research Council, *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (National Academy Press, 2000), p. 19, emphasis added.

<sup>23</sup> National Research Council, *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (National Academy Press, 2000), p. 124.

<sup>24</sup> Statement of 21<sup>st</sup> Century Science Coalition, <http://www.texasscientists.org/sign.html>.

<sup>25</sup> See discussion of this in historian Jeffery Burton Russell’s book *Inventing the Flat Earth: Columbus and Modern Historians* (Praeger, 1997).

<sup>26</sup> See John William Draper, *History of the Conflict between Religion and Science* (Appleton, 1897); Andrew Dickson White, *A History of the Warfare of Science with Theology in Christendom* (Appleton, 1898). Draper was a college professor, and White was President of Cornell University.

<sup>27</sup> See “A Preliminary Analysis of the Treatment of Evolution in Biology Textbooks currently being considered for adoption by the Texas State Board of Education” (Discovery Institute, 2003), <http://www.discovery.org/articleFiles/PDFs/TexasPrelim.pdf>; “An Analysis of the Treatment of the Scientific Controversy over Microevolution and Macroevolution in Biology Textbooks currently being considered for adoption by the Texas State Board of Education” (Discovery Institute, 2003), <http://www.discovery.org/articleFiles/PDFs/micromacro.pdf>; “An Analysis of the Treatment of Homology in Biology Textbooks currently being considered for adoption by the Texas State Board of Education” (Discovery Institute, 2003), <http://www.discovery.org/articleFiles/PDFs/homologyrpt.pdf>.

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<sup>28</sup> Charles Darwin, *On the Origin of Species*, introduction.

<sup>29</sup> Apply to Fourth Grade, standard (b)(3)(A), TEKS, Grades K-5; Fifth Grade, standard (b)(3)(A), TEKS, Grades K-5; Grade 6, standard (b)(3)(A), TEKS, Grades 6-8; Grade 7, standard (b)(3)(A), TEKS, Grades 6-8; Grade 8, standard (b)(3)(A), TEKS, Grades 6-8; Integrated Physics and Chemistry, standard (c)(3)(A), TEKS, Grades 9-12; Biology, standard (c)(3)(A), TEKS, Grades 9-12; Chemistry, standard (c)(3)(A), TEKS, Grades 9-12; Physics, standard (c)(3)(A), TEKS, Grades 9-12; Environmental Systems, standard (c)(3)(A), TEKS, Grades 9-12; Aquatic Science, standard (c)(3)(A), TEKS, Grades 9-12; Astronomy, standard (c)(3)(A), TEKS, Grades 9-12; Earth and Space Science, standard (c)(3)(A), TEKS, Grades 9-12;

<sup>30</sup> C. E. Cleland, “Historical science, experimental science, and the scientific method,” *Geology*, 29:987-990 (2001).

<sup>31</sup> Integrated Physics and Chemistry, standard (c)(5)(I), TEKS, Grades 9-12.

<sup>32</sup> Environmental Systems, standard (c)(9)(E), TEKS, Grades 9-12.

<sup>33</sup> See Integrated Physics and Chemistry, (c)(3)(E), TEKS, Grades 9-12 (“research describes the history of physics, chemistry, and contributions of scientists”—should be “research and describe”); Biology, TEKS, Grades 9-12 (no requirement); Chemistry, (c)(3)(E), TEKS, Grades 9-12 (“research and describe the history of chemistry and contributions of scientists”); Physics, (c)(3)(D), TEKS, Grades 9-12 (“describe the contributions of a variety of historical and contemporary scientists and the impacts of their research on scientific thought, society, and the environment.”); Environmental Systems, (c)(3)(E), TEKS, Grades 9-12 (“research and describe the history of environmental science and contributions of scientists”); Aquatic Science, (c)(3)(E), TEKS, Grades 9-12 (“explore and describe the history of aquatic science and contributions of scientists”).

<sup>34</sup> Astronomy, (c)(4)(A)-(C), TEKS, Grades 9-12.

<sup>35</sup> Francis Darwin, ed., *The Autobiography of Charles Darwin and Selected Letters* (Dover, 1958), pp. 42-43.

<sup>36</sup> See, for example, A. N. Whitehead, *Science and the Modern World* (The Free Press, 1967), pp. 2-4, 13; Rodney Stark, *For the Glory of God: How Monotheism Led to Reformations, Science, Witch-Hunts, and the End of Slavery* (Princeton, 2003).

<sup>37</sup> Integrated Physics and Chemistry, standard (c)(3)(C), TEKS, Grades 9-12 (“evaluate the impact of scientific research on society and the environment”); Biology, standard (c)(3)(C), TEKS, Grades 9-12 (“evaluate the impact of research on scientific thought, society, and the environment”); Chemistry, standard (c)(3)(C), TEKS, Grades 9-12 (“evaluate the impact of research on scientific thought, society, and the environment”); Physics, standard (c)(3)(D), TEKS, Grades 9-12 (“describe the contributions of a variety of historical and contemporary scientists and the impacts of their research on scientific thought, society, and the environment”); Environmental Systems, standard (c)(3)(C), TEKS, Grades 9-12 (“evaluate the impact of research on scientific thought, society, and the environment”); Aquatic Science, standard (c)(3)(C), TEKS, Grades 9-12 (“evaluate the impact of research on scientific thought, society, and the environment”); Astronomy, standard (c)(3)(C), TEKS, Grades 9-12 (“evaluate the impact of research on scientific thought, society, and the environment”); Astronomy, (c)(4)(D) (“explain the contributions of modern astronomy to today’s society”); Astronomy, standard (c)(14)(A), TEKS, Grades 9-12 (“identify and explain the contributions of human space flight, and future plans and challenges”); Earth and Space Science, standard (c)(3)(C), TEKS, Grades 9-12 (“evaluate the impact of research on scientific thought, society, and public policy”); Engineering Design and Problem Solving, standard (c)(4)(E), TEKS, Grades 9-12 (“discuss the history and importance of engineering innovation on the American economy and quality of life”).

<sup>38</sup> Stephen C. Meyer and Michael Newton Keas, “The Meanings of Evolution,” in Campbell and Meyer, editors, *Darwinism, Design, and Public Education*, pp. 135-156.

<sup>39</sup> Ernst Mayr, “Darwin’s Influence on Modern Thought,” *Scientific American*, July 2000, pp. 79-83.

<sup>40</sup> Biology standard (c)(7)(A), TEKS, Grades 9-12.

<sup>41</sup> Roger Lewin, “A Lopsided Look at Evolution,” *Science*, 241:292 (1988); Douglas Erwin, James Valentine, and J. J. Sepkoski, “A Comparative Study of Diversification Events: The Early Paleozoic versus the Mesozoic,” *Evolution*, 41:1177-86 (1987).

<sup>42</sup> R.S.K. Barnes, P. Calow & P.J.W. Olive, *The Invertebrates: A New Synthesis* (3rd ed., Blackwell Sci. Publications, 2001), pp. 9-10.

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- <sup>43</sup> Shu *et al.*, “Lower Cambrian vertebrates from south China,” *Nature*, 402:42-46 (Nov 4, 1999); Arthur Strahler, *Science and Earth History—The Evolution/Creation Controversy* (Prometheus Books, 1987), p. 408.
- <sup>44</sup> “Early Evolution of Land Plants: Phylogeny, Physiology, and Ecology of the Primary Terrestrial Radiation,” *Annual Review Ecol. Syst.*, 29:263-292 (1998).
- <sup>45</sup> Alan Cooper and Richard Fortey, “Evolutionary explosions and the phylogenetic fuse,” *Trends in Ecology and Evolution*, 13(4):151-156 (April, 1998); Alan Feduccia, “‘Big bang’ for tertiary birds?,” *Trends in Ecology and Evolution*, 18(4):172-176 (April, 2003).
- <sup>46</sup> Cooper and Fortey, “Evolutionary explosions.”
- <sup>47</sup> Stephen Jay Gould, “Is a new and general theory of evolution emerging?” *Paleobiology*, 6(1):119-130 (1980).
- <sup>48</sup> A “family tree” based on the molecule 18s RNA can be different from one based on a different molecule 28s RNA, as reported by R. Christen, et al., *EMBO Journal*, 10: 499-503 (1991); also see Antonis Rokas & Sean B. Carroll, “Bushes in the Tree of Life,” *PLOS Biology*, 4(11):1899-1904 (Nov., 2006).
- <sup>49</sup> W. F. Doolittle, “Phylogenetic Classification and the Universal Tree,” *Science*, 284: 2124-2128 (June 25, 1999).
- <sup>50</sup> W. Ford Doolittle, “Uprooting the Tree of Life,” *Scientific American*, 90-95 (February, 2000).
- <sup>51</sup> C. Woese “The Universal Ancestor,” *Proceedings of the National Academy of Sciences USA*, 95: 6854-9859 (June, 1998).
- <sup>52</sup> *Explore Evolution: The Arguments for and Against of Neo-Darwinism* (Hill House Publishers, 2007).
- <sup>53</sup> Biology, standard (c)(7)(B), TEKS, Grades 9-12.
- <sup>54</sup> Biology, standard (c)(7)(C), TEKS, Grades 9-12.
- <sup>55</sup> Biology, standard (c)(7)(D), TEKS, Grades 9-12.
- <sup>56</sup> Biology, standard (c)(7)(E), TEKS, Grades 9-12.
- <sup>57</sup> K.S. Thomson, “Macroevolution: The morphological problem,” *American Zoologist*, 32:106-112 (1992).
- <sup>58</sup> G. L. Miklos, “Emergence of organizational complexities during metazoan evolution: perspectives from molecular biology, palaeontology and neo-Darwinism,” *Mem. Ass. Australas. Palaeontols*, 15:7-41 (1993).
- <sup>59</sup> Lynn Margulis quoted in Darryl Madden, “UMass Scientist to Lead Debate on Evolutionary Theory,” *Brattleboro (Vt.) Reformer* (February 3, 2006).
- <sup>60</sup> Lynn Margulis, Dorion Sagan, *Acquiring Genomes: A Theory of the Origins of the Species* (Basic Books, 2003), p. 29.
- <sup>61</sup> S. F. Gilbert, J. M. Opitz, & R. A. Raff, “Resynthesizing evolutionary and developmental biology,” *Developmental Biology*, 173:357-372 (1996).
- <sup>62</sup> G. Webster & B. Goodwin, “A structuralist approach to morphology,” *Rivista di Biologia*, 77:503-10 (1984); N. H. Shubin & C. R. Marshall, “Fossils, genes, and the origin of novelty,” in *Deep time* (The Paleontological Society, 2000), pp. 324-340; D. H. Erwin, “Macroevolution is more than repeated rounds of microevolution,” *Evolution & Development*, 2:78-84 (2000); S. Conway Morris, “The question of metazoan monophyly and the fossil record,” *Progress in Molecular and Subcellular Biology*, 21:1-9 (1998); S. Conway Morris, “Evolution: bringing molecules into the fold,” *Cell*, 100:1-11 (2000); S. Conway Morris, “The Cambrian ‘explosion’ of metazoans,” in Muller & Newman, eds., *Origination of organismal form*, pp. 13-32; R. L. Carroll, “Towards a new evolutionary synthesis,” *Trends in Ecology and Evolution*, 15:27-32 (2000); G. P. Wagner, “What is the promise of developmental evolution? Part II: A causal explanation of evolutionary innovations may be impossible,” *Journal of Experimental Zoology (Mol. Dev. Evol.)*, 291:305-309 (2001); H. Becker & W. Lonngig, “Transposons: eukaryotic,” in *Nature encyclopedia of life sciences*, 18:529-539 (2001); B. M. R. Stadler, P. F. Stadler, G. P. Wagner, & W. Fontana, “The topology of the possible: formal spaces underlying patterns of evolutionary change,” *Journal of Theoretical Biology*, 213:241-274 (2001); W. E. Lonngig & H. Saedler, “Chromosome rearrangements and transposable elements,” *Annual Review of Genetics*, 36:389-410 (2002); G. P.

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<sup>63</sup> M. Eden, "The inadequacies of neo-Darwinian evolution as a scientific theory," in P. S. Morehead and M. M. Kaplan, eds., *Mathematical challenges to the Darwinian interpretation of evolution* (Wistar Institute Symposium Monograph, 1967), pp. 5-12; M. Schutzenberger, "Algorithms and the neo-Darwinian theory of evolution," in Morehead and Kaplan, *Mathematical Challenges*, pp. 73-75; S. Lovtrup, "Semantics, logic and vulgate neo-darwinism," *Evolutionary Theory*, 4:157-172 (1979).

<sup>64</sup> Eden, "The inadequacies of neo-Darwinian evolution"; M. Denton, *Evolution: a theory in crisis* (Adler & Adler, 1986).

<sup>65</sup> D. A. Axe, "Extreme functional sensitivity to conservative amino acid changes on enzyme exteriors," *Journal of Molecular Biology* 301(3):585-596 (2000); D. A. Axe, "Estimating the prevalence of protein sequences adopting functional enzyme folds," *Journal of Molecular Biology*, 341:1295-1315 (2004); J. Reidhaar-Olson, & R. Sauer, "Functionally acceptable solutions in two alpha-helical regions of lambda repressor," *Proteins, Structure, Function, and Genetics*, 7:306-316 (1990); M. Behe, "Experimental support for regarding functional classes of proteins to be highly isolated from each other," in J. Buell and V. Hearn, eds., *Darwinism: science or philosophy?* (Foundation for Thought and Ethics, 1992), pp. 60-71; S. Kauffman, *At home in the universe* (Oxford University Press, 1995), p. 44; W. A. Dembski, *The design inference* (Cambridge University Press, 1998), pp. 175-223.

<sup>66</sup> W. Arthur, *The origin of animal body plans* (Cambridge University Press, 1997), p. 21.

<sup>67</sup> K.S. Thomson, "Macroevolution: The morphological problem"; B. John & G. Miklos, *The eukaryote genome in development and evolution* (Allen & Unwinding, 1988), p. 309.

<sup>68</sup> John and Miklos, *The eukaryote genome*, p. 309.

<sup>69</sup> J. F. McDonald, "The molecular basis of adaptation: a critical review of relevant ideas and observations," *Annual Review of Ecology and Systematics* 14:77-102 (1983), p. 93.

<sup>70</sup> B. C. Goodwin, "What are the causes of morphogenesis?" *BioEssays*, 3:32-36 (1985); H. F. Nijhout, "Metaphors and the role of genes in development," *BioEssays*, 12:441-446 (1990); J. Sapp, *Beyond the gene* (Oxford University Press, 1987); G. B. Muller & S. A. Newman, "Origination of organismal form: the forgotten cause in evolutionary theory," in G. B. Muller & S. A. Newman, eds., *Origination of organismal form: beyond the gene in developmental and evolutionary biology* (M.I.T. Press, 2003), pp. 3-12.

<sup>71</sup> F. M. Harold, "From morphogenes to morphogenesis," *Microbiology*, 141:2765-2778 (1995), p. 2774; L. Moss, *What genes can't do* (M.I.T. Press, 2004).

<sup>72</sup> F. M. Harold, *The way of the cell: molecules, organisms, and the order of life* (Oxford University Press, 2001), p. 125.

<sup>73</sup> Biology, standard (c)(6)(D), TEKS, Grades 9-12.

<sup>74</sup> Robin D. Knight, Stephen J. Freeland, and Laura F. Landweber, "Rewiring the Keyboard: Evolvability of the Genetic Code," *Nature Reviews Genetics*, 2:49-58 (2001); Catherine A. Lozupone, Robin D. Knight and Laura F. Landweber, "The molecular basis of nuclear genetic code change in ciliates," *Current Biology*, 11: 65-74 (2001); Patrick J. Keeling and W. Ford Doolittle, "Widespread and Ancient Distribution of a Noncanonical Genetic Code in Diplomonads," *Molecular Biology and Evolution*, 14:895-901(1997); A. Baroin-Tourancheau, N. Tsao, L.A. Klobutcher, R.E. Pearlman, and A. Adoutte, "Genetic code deviations in the ciliates: evidence for multiple and independent events," *EMBO Journal*, 14: 3262-3267 (1995); Andrew L. Karamyshev, Koichi Ito, and Yoshikazu Nakamura, "Polypeptide release factor eRF1 from *Tetrahymena thermophila*: cDNA cloning, purification and complex formation with yeast eRF3," *FEBS Letters*, 457:483-488 (1999), p. 485; Mark Ridley, *The Problems of Evolution* (Oxford: Oxford University Press, 1985), pp. 10-11; Brian Charlesworth, "Darwinism is alive and well," review of *The Problems of Evolution*, *New Scientist*, July 11, 1985, p. 58.

<sup>75</sup> Niles Lehman, "Please release me, genetic code," *Current Biology*, 11: R63-R66 (2001), p. R63.

<sup>76</sup> Biology, standard (c)(6)(D), TEKS, Grades 9-12.

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<sup>77</sup> R. von Sternberg & J.A. Shapiro, "How repeated retroelements format genome function," *Cytogenetic and Genome Research*, 110:108–116 (2005); J.S. Han, S.T. Szak, and J.D. Boeke, "Transcriptional disruption by the L1 retrotransposon and implications for mammalian transcriptomes," *Nature*, 429:268–274 (2004); B.A. Janowski, K. E. Huffman, J. C. Schwartz, R. Ram, D. Hardy, D. S. Shames, J. D. Minna, and D. R. Corey, "Inhibiting gene expression at transcription start sites in chromosomal DNA with antigene RNAs" *Nature Chemical Biology*, 1:216–222 (2005); J. A. Goodrich, and J. F. Kugel, "Non-coding-RNA regulators of RNA polymerase II transcription," *Nature Reviews Molecular and Cell Biology*, 7: 612–616 (2006); L.C. Li, S. T. Okino, H. Zhao, H., D. Pookot, R. F. Place, S. Urakami, H. Enokida, and R. Dahiya, "Small dsRNAs induce transcriptional activation in human cells," *Proceedings of the National Academy of Sciences USA*, 103:17337–17342 (2006); Pagano, M. Castelnuovo, F. Tortelli, R. Ferrari, G. Dieci, and R. Cancedda, "New small nuclear RNA gene-like transcriptional units as sources of regulatory transcripts," *PLoS Genetics*, 3: e1. (2007); L. N. van de Lagemaat, J. R. Landry, D. L. Mager, P. Medstrand, "Transposable elements in mammals promote regulatory variation and diversification of genes with specialized functions," *Trends in Genetics*, 19:530–536 (2003); S. R. Donnelly, T. E. Hawkins, S. E. Moss, "A Conserved nuclear element with a role in mammalian gene regulation," *Human Molecular Genetics*, 8(9):1723–1728 (1999); C. A. Dunn, P. Medstrand, and D. L. Mager, "An endogenous retroviral long terminal repeat is the dominant promoter for human B1,3- galactosyltransferase 5 in the colon," *Proceedings of the National Academy of Sciences USA*, 100(22):12841–12846 (October 28, 2003); B. Burgess-Beusse, C. Farrell, M. Gaszner, M. Litt, V. Mutskov, F. Recillas-Targa, M. Simpson, A. West, and G. Felsenfeld, "The insulation of genes from external enhancers and silencing chromatin," *Proceedings of the National Academy of Sciences USA*, 99(4):16433–16437 (December 10, 2002); P. Medstrand, Josette-Rene'e Landry, and D. L. Mager, "Long Terminal Repeats Are Used as Alternative Promoters for the Endothelin B Receptor and Apolipoprotein C-I Genes in Humans," *Journal of Biological Chemistry*, 276(3):1896–1903 (January 19, 2001); L. Mariño-Ramírez, K.C. Lewis, D. Landsmana, and I.K. Jordan, "Transposable elements donate lineage-specific regulatory sequences to host genomes," *Cytogenetic and Genome Research*, 110(1-4):333–341 (2005); Richard W. McKenzie and Mark D. Brennan, "The two small introns of the *Drosophila affinis* *Adh* gene are required for normal transcription," *Nucleic Acids Research*, 24(18) (1996):3635–3642; Phillipe Arnaud, Chantal Goubely, Thierry Pe'Lissier, and Jean-Marc Deragon, "SINE Retroposons Can Be Used In Vivo as Nucleation Centers for De Novo Methylation," *Molecular and Cellular Biology*, 20(10):3434–3441 (May 2000); C. M. Rubin, R.H. Kimura & C.W. Schmid, "Selective stimulation of translational expression by Alu RNA," *Nucleic Acids Research*, 30: 3253–3261 (2002); D. Bartel, "MicroRNAs: Genomics, biogenesis, mechanism, and function," *Cell*, 116: 281–297 (2004); J.S. Mattick, and I.V. Makunin, "Small regulatory RNAs in mammals," *Human Molecular Genetics*, 14: R121–R132 (2005).

<sup>78</sup> Earth and Space Science, standard (c)(8)(A), TEKS, Grades 9-12.

<sup>79</sup> Ibid.

<sup>80</sup> Edward Anders. "Pre-biotic organic matter from comets and asteroids." *Nature*, 342:255-257 (November 16, 1989).

<sup>81</sup> Adam P. Johnson, H. James Cleaves, Jason P. Dworkin, Daniel P. Glavin, Antonio Lazcano, Jeffrey L. Bada, "The Miller Volcanic Spark Discharge Experiment," *Science* 322:404 (October 17, 2008); David Deamer, "The First Living Systems: a Bioenergetic Perspective," *Microbiology & Molecular Biology Reviews*, 61(2):239-261 (June, 1997).

<sup>82</sup> Bernd-Olaf Koppers, *Information and the Origin of Life* (Cambridge: MIT Press, 1990), pp. 170–172.

## APPENDIX

### List of Recommendations

*Note: Proposed new language to be added to the TEKS is underlined.*

#### **Definition of Science**

**Recommendation:** Throughout the TEKS,<sup>1</sup> add the following language to the definition of science standard wherever it appears: “Students should know that scientific ‘[i]nquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations’”; OR “Students should know that scientific inquiry requires ‘the critical abilities of analyzing an argument by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models are best.’”

**Recommendation:** Remove language from the TEKS about “purported forces... outside of nature” and the language equating testing with refutability. If there is a desire for students to learn about debates among philosophers of science about the definition of science, the following new language can be inserted: “Students should know about debates among scientists and philosophers of science about the definition of science.”

**Recommendation:** Remove the disclaimer in high school Biology standard (b)(5) stating that “[m]any theories in science are so well established that no new evidence is likely to alter them substantially” and make the standard consistent with the language in the rest of the high school standards.

**Recommendation:** Add the following language to the relevant standards<sup>2</sup> in section (b) of the TEKS for grades 9-12: “The history of science shows that the prevailing consensus among scientists may turn out be correct, but it may also turn out to be incorrect, and so even prevailing scientific theories should be open to continuing refinement, evaluation, and refutation.”

#### **Critical Thinking**

**Recommendation:** Create a uniform version of the critical thinking standard that applies across grades and courses,<sup>3</sup> modifying the “strengths and weaknesses” language as follows: “analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using empirical evidence, logical reasoning, experimental and/or observational testing.”

**Recommendation:** Modify high school Environmental Systems standard (c)(9)(B) to read: “analyze the strengths and weaknesses of scientific hypotheses about the

effect of pollution on global warming, glacial/ice cap melting, greenhouse effect, ozone layer, and aquatic viability.”

**Recommendation:** Modify high school Environmental Systems standard (c)(9)(C) to read: “analyze the strengths and weaknesses of scientific hypotheses about the effect of recreational activities such as, hunting, fishing, ecotourism, all terrain vehicles, and small personal water craft on the environment.”

**Recommendation:** Modify high school Environmental Systems standard (c)(9)(F) to read: “analyze the strengths and weaknesses of local, state and national legislation and international treaties/protocols including, Texas automobile emissions regulations, National Park Service Act, and Kyoto Protocol.”

**Recommendation:** Modify high school Aquatic Science standard (c)(12)(D) to read: “analyze the strengths and weaknesses of scientific hypotheses about how human activities such as fishing, transportation, dams, and recreation have influenced aquatic environments.”

**Recommendation:** Modify high school Aquatic Science standard (c)(12)(E) to read: “understand the arguments about positive and negative impacts of various laws and policies (such as The Endangered Species Act, right of capture laws, or Clean Water Act) on aquatic systems and society.”

**Recommendation:** Modify high school Astronomy standard (c)(13)(C) to read: “analyze the strengths and weaknesses of scientific hypotheses about the fate of the universe, including open and closed universe models, dark matter, and dark energy.”

**Recommendation:** Modify high school Earth and Space Science standard (c)(4)(A) to read: “evaluate the strengths and weaknesses of the arguments for the Big Bang model that reveals an expanding universe originating from an initial singularity about 14 billion years ago.”

**Recommendation:** Modify high school Earth and Space Science standard (c)(6)(A) to read: “analyze the strengths and weaknesses of the arguments for the evolution of Earth’s atmosphere over time from the original protoplanet hydrogen-helium atmosphere, the carbon dioxide-water vapor-methane atmosphere, and the current nitrogen-oxygen atmosphere.”

**Recommendation:** Modify high school Earth and Space Science standard (c)(6)(B) to read: “evaluate the evidence for the hypothesis that volcanic outgassing and the impact of water-bearing comets have played a major role in creating Earth’s atmosphere and hydrosphere.”

**Recommendation:** Modify high school Earth and Space Science standard (c)(6)(D) to read: “evaluate the evidence for the hypothesis that the Earth’s cooling led to tectonic activity, resulting in continents and ocean basins.”

**Recommendation:** Modify high school Earth and Space Science standard (c)(8)(B) to read: “evaluate a variety of fossil types, significant fossil deposits and proposed transitional fossils and fossil lineages, and assess the arguments for and against universal common descent in light of this fossil evidence.”

**Recommendation:** Modify high school Earth and Space Science standard (c)(13)(D) to read: “analyze the strengths and weaknesses of hypotheses about the effects of the following factors and mechanisms on changes in the Earth’s climate: atmospheric carbon dioxide concentration, major volcanic eruptions, changes in solar luminance, giant meteorite impacts, and human activities.”

### **History and Social Impact of Science**

**Recommendation:** Modify the history of science standard that typically appears in section (c)(3) of each set of TEKS to require students to learn about the cultural (political, economic, intellectual, religious) factors that influenced the development of modern science.

**Recommendation:** Revise the main standard on the impact of science on society in each high school course (typically standard (c)(3)(C)) to require students to learn about both the positive and negative social impacts of science in the discipline under study. Examples of key positive and negative impacts also should be provided.

### **High School Biology**

**Recommendation:** Modify high school Biology standard (c)(3)(C) to read: “evaluate the positive and negative impacts of biological research on society by studying examples from history including the germ theory of disease, the development of antibiotics, eugenics, the Tuskegee syphilis experiment, and theories of scientific racism.”

**Recommendation:** Insert the following additional standard under section (c)(7) of the high school Biology standards: “know and distinguish between the different meanings of the term evolution, including change over time, universal common ancestry, and natural selection acting on random variations; and understand that evolutionary biology is primarily an historical science.”

**Recommendation:** Modify Biology standard (c)(7)(A) to read: “analyze, review, and critique the strengths and weaknesses of the arguments for universal common ancestry including those based upon the fossil record, biogeography, molecular and anatomical homology, and developmental biology.”

**Recommendation:** Modify high school Biology standard (c)(7)(D) to read: “analyze the strengths and weaknesses of arguments for the ability of natural selection to produce new adaptations and a diversity of species, as well as higher taxonomic groups and new body plans.”

**Recommendation:** Modify high school Biology standard (c)(7)(E) to read: “analyze the strengths and weaknesses of arguments for the ability of other evolutionary mechanisms including genetic drift, gene flow, mutation, and recombination to produce significant evolutionary change”

**Recommendation:** Modify high school Biology standard (c)(6)(B) to read: “recognize that the genetic code is similar in most organisms but that there are variations in the genetic code. Analyze whether this evidence supports or challenges the theory of universal common ancestry.”

**Recommendation:** Modify high school Biology standard (c)(6)(D) to read: “recognize that the genome contains both protein-coding and non-protein-coding DNA and that gene expression is a process regulated largely by non-coding DNA.”

**Recommendation:** Add a high school Biology standard about the origin of life: “analyze, review, and critique the strengths and weaknesses of various hypotheses about the origin of life, including those involving a pre-biotic soup. Specifically, evaluate the ability of these hypotheses to explain the origin of: organic monomers under primitive Earth conditions; the origin of complex biopolymers such as proteins, RNA, or DNA; the origin of sequence-specific information in proteins, RNA and DNA; and the origin of a primitive self-replicating life-form.”

### **High School Earth and Space Science**

**Recommendation:** Substitute the following wording for high school Earth and Space Science standard (c)(8)(A) about the origin of life: “analyze, review, and critique the strengths and weaknesses of various hypotheses about the origin of life, including those involving a pre-biotic soup, hydrothermal steam vents, and the transport of organic chemicals to Earth by comets. Specifically, evaluate the ability of these hypotheses to explain the origin of: organic monomers under primitive Earth conditions; the origin of complex biopolymers such as proteins, RNA, or DNA; the origin of sequence-specific information in proteins, RNA and DNA; the origin of the modern genetic code system; the origin of a primitive self-replicating

life-form; and the origin of a minimally complex free-living cell.”

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<sup>1</sup> Add to Integrated Physics and Chemistry, standard (b)(2), TEKS, Grades 9-12; Biology, standard (b)(2), TEKS, Grades 9-12; Chemistry, standard (b)(2), TEKS, Grades 9-12; Physics, standard (b)(2), TEKS, Grades 9-12; Environmental Systems, standard (b)(2), TEKS, Grades 9-12; Aquatic Science, standard (b)(2), TEKS, Grades 9-12; Astronomy, standard (b)(2), TEKS, Grades 9-12; Kindergarten, standard (a)(3), TEKS, Grades K-5; Grade 1, standard (a)(3), TEKS, Grades K-5; Grade 2, standard (a)(3), TEKS, Grades K-5; Grade 3, standard (a)(4), TEKS, Grades K-5. Also add to the TEKS for grades 4-8 if the definition of science in those grades is made consistent with the definition offered elsewhere in the TEKS.

<sup>2</sup> Integrated Physics and Chemistry, standard (b)(2) or (b)(4), TEKS, Grades 9-12; Biology, standard (b)(5), TEKS, Grades 9-12; Chemistry, standard (b)(2), TEKS, Grades 9-12; Physics, standard (b)(2), TEKS, Grades 9-12; Environmental Systems, standard (b)(2) or (b)(5), TEKS, Grades 9-12; Aquatic Science, standard (b)(2) or (b)(4) or (b)(5), TEKS, Grades 9-12; Astronomy, standard (b)(2) or (b)(4), TEKS, Grades 9-12; Earth and Space Science, standard (b)(7), TEKS, Grades 9-12.

<sup>3</sup> Apply to Fourth Grade, standard (b)(3)(A), TEKS, Grades K-5; Fifth Grade, standard (b)(3)(A), TEKS, Grades K-5; Grade 6, standard (b)(3)(A), TEKS, Grades 6-8; Grade 7, standard (b)(3)(A), TEKS, Grades 6-8; Grade 8, standard (b)(3)(A), TEKS, Grades 6-8; Integrated Physics and Chemistry, standard (c)(3)(A), TEKS, Grades 9-12; Biology, standard (c)(3)(A), TEKS, Grades 9-12; Chemistry, standard (c)(3)(A), TEKS, Grades 9-12; Physics, standard (c)(3)(A), TEKS, Grades 9-12; Environmental Systems, standard (c)(3)(A), TEKS, Grades 9-12; Aquatic Science, standard (c)(3)(A), TEKS, Grades 9-12; Astronomy, standard (c)(3)(A), TEKS, Grades 9-12; Earth and Space Science, standard (c)(3)(A), TEKS, Grades 9-12;