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Science standards: The foundation of evolution education in the United States

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Abstract Science standards and textbooks have a huge impact on the manner in which evolution is taught in American classrooms. Standards dictate how much time and what points have to be dedicated to the subject in order to prepare students for state-wide assessments, while the textbooks will largely determine how the subject is presented in the classroom. In the United States both standards and textbooks are determined at the state-level through a political process. Currently there is a tremendous amount of pressure arising from anti-evolutionists in the United States to weaken or omit the teaching of evolution despite recommendations from central institutions such as the National Academy of Science. Results from the Program for International Student Assessment (PISA) showed that not only are American students performing below average, but also that their performance is declining as they scored worse in 2012 than they did in 2010. Interestingly PISA also found that the internal variation within a country is often greater than between countries with a variation of up to 300 points, which is equivalent to seven years of education pointing to the extreme heterogeneous quality of education within a country (OECD, 2012). An implementation of strong standards would not only help to increase the average performance of American students but could also alleviate the vast discrepancy between the highest and lowest scoring groups of American students. Although the *Next Generation Science Standards* have been in existence since 2013 and *A Framework for K-12 Science Education* has been available to the public since 2011 many American states still continue to create their own standards that, according to the Fordham study, are well below par (Lerner et al., 2012). Due to the political nature of the adoption procedure of standards and textbooks, there are many opportunities for interested individuals to get involved in the process of improving these fundamental elements of science education.
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Abbreviations: ACT, American College Testing Program; AAAS, American Association for the Advancement of Science; NCSE, National Center for Science Education; NGSS, Next Generation Science Standards; SBOE, State Board of Education; TEA, Texas Education Agency; TEKS, Texas Essential Knowledge and Skills.

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Introduction

An organized movement against the teaching of evolution in public schools has been present in the United States since the 1920s (Numbers, 2009). Unlike other countries, the American school system is not regulated by the national government but is instead largely dictated by state-level decisions, which means that public education in the United States varies greatly state to state since the lack of a nationally centralized curriculum or education standards means that each state has the ability to determine its own standards (USNEI, 2008). Of course these standards are similar in some aspects but can differ greatly when it comes to controversial subjects like evolution (Padian, 2010).

The decision about curriculum is made by committees and boards of elected individuals (USNEI, 2008). The fact that these decision-making individuals are elected, and thus have responsibilities to represent the desires of their constituents, means that local individuals can get involved in helping determine the state standards through political activity. The ability for individuals to affect change to the education system is particularly relevant for science education in the United States since polls have shown that one in three American adults rejects the theory of evolution as a suitable explanation for life on Earth (Miller et al., 2006) and 40 percent of Americans believe that the earth was created through supernatural forces within the last six to ten thousand years (Blancke and Smedt, 2013; Newport, 2010).

This opportunity to affect statewide science standards has in fact become a relatively new target for Darwin doubters; one that has a broader impact than local school-board decisions as Glenn Branch of the *National Center for Science Education* describes, ''Savvy creationists are focusing their efforts on this relatively new arena (Wallis, 2005, p. 55).'' And they are succeeding — the Fordham Institute published a report in 2012 about state science standards in the United States and found that the most important weakness in the science standards is how evolution is undermined and presented as a weak scientific theory in many states. They further found that although some states are teaching evolution better than they did in the past, the increasing pressure from anti-evolution groups continues to pose a serious threat to science standards in the United States (Lerner et al., 2012). This attempt to weaken the teaching of evolution by trying to emphasize the weaknesses and gaps in evolution is in essence the crux of the intelligent design movement (Wallis, 2005). For anyone who believes that intelligent design is less harmful to science education than its older cousin, creationism, must understand that intelligent design may be the most potent and dangerous version of creationism yet and it is a major threat to the scientific education of American students (Blancke, 2014; Forrest, 2007). This threat to science education is particularly relevant in the United States, since studies have shown that 69% of American students failed to meet the ACT's college readiness benchmarks for science (ACT, 2012).

To understand, just how fast and wide spread the effects of these political decisions can be, one can simply look at what happened in Kansas in 1999 when the State Board of Education voted to completely remove evolution from the state science standards and pursue a science curriculum that omits evolution (Cunningham, 1999). Although the omission from the science standards does not prohibit the teaching of evolution, by removing it from the state curriculum and thus from state assessment tests, it may discourage school districts from investing any time or money in teaching the subject (Belluck, 1999). The decision was protested by the scientific and education communities (Good et al., 2001). In 2001, the power of the citizens of Kansas was again evident when they were given the opportunity to elect different representatives and the newly-seated Kansas State Board of Education voted to restore the teaching of evolution to the state science standards, a decision that was applauded by the *American Association for the Advancement of Science*, the *National Academy of Sciences* and *National Research Council*, and the *National Science Teachers Association* (NCSE, 2001). This situation illustrates how much influence the citizens have in affecting the science standards and thus science education within their state through their ability to vote for representatives that will reflect their interests in either direction.

Evolution and biological education in America

Thus, the Americans' views on evolution have a direct effect on science education in the United States through their ability to vote for representatives and to lobby to directly affect decisions regarding science standards. For that reason it is important to understand where the Americans stand regarding the teaching of evolution. In 2000, the People for the American Way conducted a survey following the Kansas decision in 1999 and found that the United States population is in fact very divided regarding the teaching of evolution as can be seen in Table 1 (People For the American Way Foundation, 2000).

It is important to note here the very small percentage of people who either do not have any opinion (1%) or are unsure of how the subject should be dealt with (4%). Meaning that 95% of the American population has a specific opinion about how evolution should or should not be taught in public schools (Table 1).

This is an important factor to consider since as mentioned above, state standards and textbook selections are decided by groups of elected individuals who are responsible for representing their constituents' opinions. By creating standards that strongly emphasize evolution, they would thus run the risk of alienating large portions of the population. To get a better understanding of how exactly state standards are

Table 1 American citizens' views on teaching creationism and evolution in science classes according to People for the American Way Foundation.

Only evolution/no Creationism in science class[a]	37%
Creationism/Intelligent Design with or instead of evolution in science class[b]	58%
Unsure or no opinion	5%

[a] 17% believe that evolution belongs in the science classroom and religious theories should be taught elsewhere combined with 20% who are for a pure science education.

[b] 16% believe that public schools should teach only Creationism plus 29% who believe that it is okay to mention Creationism plus 13% who believe that both should be taught.

decided, we will look at two specific states as examples: Texas and California.[1] It is of value to pay attention to the political nature of these decisions and actions.

First a state must determine how many years of science a student is required to attend at a public high school to meet graduation requirements (Blackwell et al., 2003). The state is then mandated to create standards that are to be taught within those classes. Some national associations in the United States have created projects to assist states in creating science curriculum standards. The *American Association for the Advancement of Science* (AAAS) for instance has developed a long-term research and education initiative called ''Project 2061[2]'' that is focused on increasing science literacy in the United States. Part of this project was the creation of the *Next Generation Science Standards* (NGSS) that are based on the *Framework for K-12 Science Education*[3] as put forth by the *National Research Council*. The NGSS provide clear guidelines about what is recommended for education about evolution. In the section, Natural Selection and Evolution for High Schools, it describes what a student should understand about evolution (Table 2).

Notice here that the guidelines do not only specify what points should be taught (i.e. natural selection, heredity, etc.) but specifically delineate what abilities a student should obtain (e.g. ability to explain, communicate, evaluate, etc.). As great as such projects are, they still remain only guidelines and not requirements. The AAAS within the framework of Project 2061 also offers assessment services and workshops to help states create science standards that are in line with the AAAS recommendations, but again, this is ultimately up to the states. Furthermore, the NGSS website explicitly points out that the standards should be adopted as a whole and not in pieces and that states would then need to offer assistance to the local school districts in order to help them implement the science standards into the district's curricula.[4] As they state, quality science education is based on standards that are rich in both content and practice and curricula that are aligned to these standards (NGSS, 2013).

In theory, a state could easily adopt the entire NGSS as their state science standards, yet despite the accessibility of these centralized guidelines that are defined by central science associations, science standards still differ greatly state to state (OECD, 2012). The reason for the heterogeneous nature of science standards rests upon the fact that these standards are created through political processes and not through centralized scientific agencies. Here it is important to emphasize that the persons responsible for deciding and ''approving state science standards tend to be small, not particularly knowledgeable and, above all, elected, so it's a good opportunity for political pressure to be applied (Wallis, 2005, p. 55).''

The Texas and California science standards as a case study

The adoption process for such standards is complex and involves many different steps and government entities. For example, the Texas Education Agency (TEA)[5] has published the review process for their state educational standards, called the Texas Essential Knowledge and Skills (TEKS), online describing a complicated process consisting of 22 steps involving the cooperation between the public, the TEKS review board, the State Board of Education (SBOE), Texas Association of School Boards (TASB) and the TEA.

It is noteworthy how many steps are involved in the process and the amount of information that is provided to the public in order for them to offer their feedback to the state agencies. It is also very noteworthy that there is no specific mention of requesting feedback or guidance from any to the national level associations or centralized science institutions. Again this points to how much state standards are driven by local populations and not by national agencies or science authorities. For a full description of the process see the Texas Education Agency website (http://tea.texas.gov).

After a state like Texas has completed their selection process, the new standards go into effect for the coming school year. Below is an example of the current TEKS for science. These standards when in effect provide the basis for curriculum in all public schools in Texas (Table 3).

In order to understand how much state standards may differ from one another, the next table provides an overview of the California Science Standards that pertain to evolution (Table 4). Here it is important to notice two main differences to the Texas Standards: (1) the amount of text and details and (2) the language used when describing what students should be able to do. For instance the Texas standards use the obscure phrase ''analyze and evaluate'' whereas California standards explicitly state that ''students know why''.

The next table shows a direct comparison between the suggested Next Generation Science Standards and the California and Texas science standards (Table 5). Although both states do cover many of the recommended topics, the language about what is expected from the students is very decisive. While the NGSS and California standards specifically say that the students are expected to understand evolution as a truth, the Texas standards state simply that the students should evaluate the principles for the ''scientific explanation for the unity and diversity of life.[6]'' This ambiguous language allows school boards in Texas to have more flexibility when determining their school curriculum and thus a higher level of heterogeneity regarding the quality of science education within the state. The detailed

[1] Texas and California were chosen as example states since both of them are textbook adoption states and both have had public conflicts regarding Creationism.

[2] The name of the project is based on the orbit of Haley's comet, which will be visible again in 2061.

[3] K-12 refers to Kindergarten to 12th grade. Although there are many differences among the states, these are normally the years of compulsory education in the United States.

[4] New Generation Science www.nextgenscience.org (Accessed February 29, 2016).

[5] Texas Education Agency: http://tea.texas.gov (Accessed February 29, 2016).

[6] *Chapter 112. Texas Essential Knowledge and Skills for Science Subchapter C. High School* published by the Texas Education Agency in August 2010 (see Table 3). http://ritter.tea.state.tx.us/rules/tac/chapter112/ch112c.html#112.34 (Accessed April 24, 2016).

Table 2 Next Generation Science Standards.

Students who demonstrate understanding of Natural Selection and Evolution can (NGSS, 2013)	
HS-LS4-1[a]	Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence. [Clarification Statement: Emphasis is on a conceptual understanding of the role each line of evidence has relating to common ancestry and biological evolution. Examples of evidence could include similarities in DNA sequences, anatomical structures, and order of appearance of structures in embryological development.]
HS-LS4-2	Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment. [Clarification Statement: Emphasis is on using evidence to explain the influence each of the four factors has on number of organisms, behaviors, morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models such as simple distribution graphs and proportional reasoning.] [*Assessment Boundary: Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and co-evolution.*]
HS-LS4-3	Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait. [Clarification Statement: Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations.] [*Assessment Boundary: Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.*]
HS-LS4-4	Construct an explanation based on evidence for how natural selection leads to adaptation of populations. [Clarification Statement: Emphasis is on using data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or evolution of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations.]
HS-LS4-5	Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species. [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.]

[a] HS-LS4 stands for High School Life Science section 4.

Table 3 Texas science standards for evolution.[a]

(7) Science concepts. The student knows evolutionary theory is a scientific explanation for the unity and diversity of life. The student is expected to:

(A) analyze and evaluate how evidence of common ancestry among groups is provided by the fossil record, biogeography, and homologies, including anatomical, molecular, and developmental;

(B) analyze and evaluate scientific explanations concerning any data of sudden appearance, stasis, and sequential nature of groups in the fossil record;

(C) analyze and evaluate how natural selection produces change in populations, not individuals;

(D) analyze and evaluate how 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, result in differential reproductive success;

(E) analyze and evaluate the relationship of natural selection to adaptation and to the development of diversity in and among species;

(F) analyze and evaluate the effects of other evolutionary mechanisms, including genetic drift, gene flow, mutation, and recombination; and

(G) analyze and evaluate scientific explanations concerning the complexity of the cell.

[a] According to *Chapter 112. Texas Essential Knowledge and Skills for Science Subchapter C. High School* published by the Texas Education Agency in August 2010. http://ritter.tea.state.tx.us/rules/tac/chapter112/ch112c.html#112.34 (Accessed April 24, 2016).

Table 4 California science standards for evolution.[a]

7. The frequency of an allele in a gene pool of a population depends on many factors and may be stable or unstable over time. As a basis for understanding this concept:
   a. Students know why natural selection acts on the phenotype rather than the genotype of an organism.
   b. Students know why alleles that are lethal in a homozygous individual may be carried in a heterozygote and thus maintained in a gene pool.
   c. Students know new mutations are constantly being generated in a gene pool.
   d. Students know variation within a species increases the likelihood that at least some members of a species will survive under changed environmental conditions.
   e.* Students know the conditions for Hardy—Weinberg equilibrium in a population and why these conditions are not likely to appear in nature.
   f.*Students know how to solve the Hardy—Weinberg equation to predict the frequency of genotypes in a population, given the frequency of phenotypes.
8. Evolution is the result of genetic changes that occur in constantly changing environments. As a basis for understanding this concept:
   a. Students know how natural selection determines the differential survival of groups of organisms.
   b. Students know a great diversity of species increases the chance that at least some organisms survive major changes in the environment.
   c. Students know the effects of genetic drift on the diversity of organisms in a population.
   d. Students know reproductive or geographic isolation affects speciation.
   e. Students know how to analyze fossil evidence with regard to biological diversity, episodic speciation, and mass extinction.
   f.*Students know how to use comparative embryology, DNA or protein sequence comparisons, and other independent sources of data to create a branching diagram (cladogram) that shows probable evolutionary relationships.
   g.*[b] Students know how several independent molecular clocks, calibrated against each other and combined with evidence from the fossil record, can help to estimate how long ago various groups of organisms diverged evolutionarily from one another.

[a] *Science Content Standards for California Public Schools Kindergarten Through Grade Twelve*. Online 2009 pg 54—55. Adopted by the California State Board of Education in 1998, published in 2000, reprinted in 2008 and posted online in 2009. PDF available at http://www.cde.ca.gov/be/st/ss/documents/sciencestnd.pdf (Accessed July 24, 2016).

[b] Meaning of (*): ''In grades nine through twelve, standards that all students are expected to achieve in their science courses are unmarked; standards that all students should have the opportunity to learn in those courses are marked with an asterisk (*). Those opportunities should be offered at every high school''. *Science Content Standards for California Public Schools Kindergarten Through Grade Twelve* (2009) pg 40. PDF available at http://www.cde.ca.gov/be/st/ss/documents/sciencestnd.pdf (Accessed April 24, 2014).

Table 5 Comparison of standards.

NGSS	Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
California	8. Evolution is the result of genetic changes that occur in constantly changing environments. As a basis for understanding this concept: a. Students know how natural selection determines the differential survival of groups of organisms. b. Students know a great diversity of species increases the chance that at least some organisms survive major changes in the environment. c. Students know the effects of genetic drift on the diversity of organisms in a population. d. Students know reproductive or geographic isolation affects speciation.
Texas	(7) Science concepts. The student knows evolutionary theory is a scientific explanation for the unity and diversity of life. The student is expected to: (C) analyze and evaluate how natural selection produces change in populations, not individuals; (D) analyze and evaluate how 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, result in differential reproductive success.

Table 6 State of state science standards 2012 Fordham review.

	California	Texas
Overall grade	A (10/10)	C (6/10)
General assessment	The California science standards are truly excellent. The standards themselves are reasonably succinct yet quite comprehensive.	Texas has produced a set of science standards with areas of strengths — including a particularly well-done sequence for earth and space science — but also with weaknesses that cannot be overlooked. These include a tendency across nearly all disciplines to pay lip service to critical content with vague statements, and, somewhat less often, the presence of material that's well below grade level.
Content & Rigor	The authors of the California standards knew what was important to cover and how to set it down in cogent prose. The material is suitably rigorous throughout, with few, if any, gaps. (7/7)	Systematic progress is evident from grade to grade, but in several disciplines the content statements are poorly developed, leaving too much to the imagination. Bringing a bit more detail to the document would go a long way toward improving the Texas standards. (5/7)
Clarity & Specificity	Not only are statements set forth clearly and cogently, with very few exceptions, but the entire document shows a solid sense of interconnection. One topic flows into another in transparent fashion, showing that the writers knew their subject matter well. (3/3)	The chief problem with the Texas standards is the lack of a red pencil. There are many clear and specific standards, but these are choked by thickets of wordy and repetitious language. In addition, the standards are sometimes confusing and frustratingly vague. (1/3)

California standards, on the other hand, do not allow as much leeway but instead require all school boards in the state to fulfill these guidelines, which should lead to higher scientific literacy in all state schools.

The differences in the standards may be traced back to the selection process of the standards. As described above, the TEKS are decided through local government agencies and places a strong emphasis on gaining feedback from the local populations. The California State Board of Education on the other hand clearly incorporated the information provided by the *National Science Education Standards* and the information they gathered from local community meetings and public hearings as they have described:

> ''The California State Board of Education and the Academic Standards Commission reviewed the National Science Education Standards, the Benchmarks for Science Literacy, and science standards and frameworks from numerous local school districts in California, from around the country, and from other nations with successful science education programs. In addition, hundreds of pages of written recommendations and hundreds of hours of testimony were considered. The Academic Standards Commission hosted nine community meetings, and the State Board of Education held five public hearings throughout California. Families, educators, and business and community leaders participated and helped define key issues. Expert reviewers around the nation submitted formal comments on the drafts and also participated in invited public testimony. Their ideas contributed substantively to the final standards adopted by the State Board of Education.''

The Fordham Institute published a report which provided a grading of the science standards in 2012 and based on their reviews they awarded California with an ''A'' and Texas with a ''C''. The grades were based on two categories: Content & Rigor (7 points) and Clarity & Specificity (3 points). California scored 10/10 points, the highest of all states and the only state to score an ''A'' in 2012 (Table 6). Six states, including California, scored an ''A'' in the 2005 report but the other five states received lower grades in 2012. Texas on the other hand had scored an ''F'' in 2005 and worked itself up to a ''C'' in 2012, well above many states, which scored a ''D'' or an ''F'' in 2012 (Lerner et al., 2012). For a full review see ''The State of State Science Standards 2012'' by the Thomas B. Fordham Institute.

In the end, the flexibility offered by the ambiguous language seen in the TEKS allows a higher amount of control at the local level since the larger amount of flexibility gives school boards more leeway in creating district wide curricula and enables the school boards to respond to the local requests of their constituents. While the NGSS has provided states with support to create superior science standards, the Discovery Institute, a think-tank in Seattle that supports the promotion of intelligent design, is providing materials for individuals to use in local forums to accomplish the exact opposite. These documents that the Discovery Institute provides are scientifically abstruse, jargon-heavy documents that make it hard for the average citizen to follow but since the people who make up the decision committees tend to be small and from non-science backgrounds, this is an optimal place to use smoke and mirrors to affect political decisions (Basel et al., 2013; Wallis, 2005; Williams, 2015).

Conclusion

State science standards have a huge influence on the way in which evolution (and other scientific subjects) is presented to students in the United States. Ultimately, high school biology teachers cannot be expected to research all aspects of biology from scholarly journals in order to prepare for their classes and thus they must rely upon the tools provided to them by governmental agencies. While well-written science standards, excellent textbooks and comprehensive curricula can be an extraordinary asset for a biology teacher and thus a blessing to science students, this is not the case in all states (Schilders et al., 2009; Tshuma and Sanders, 2015).

In some states, despite the efforts to create quality science standards, the increasing amount of political pressure from anti-evolutionists has led to the introduction of obtuse language into the standards. This obtuse language allows more leeway for schools to omit evolution from the curriculum or teach alternative creationist theories. This is detrimental to science education in general as students are denied the chance to understand one of the most fundamental scientific theories that allows us to understand the foundations of the living world (Good et al., 2001).

Thus, it is imperative that there is a movement toward centralized science standards that are constructed and reviewed by central scientific agencies. The process of deciding science standards through political processes that are reliant upon placating to public opinion has led not only to the adoption of weak standards but a general lack of science competency that is permeating the current American school system. One can only hope that more states will heed the advice set by the NGSS so that science standards can be created that will stop and reverse this dangerous trend toward science illiteracy in the United States.

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