The State of State Science Standards

2012

State reviews by Lawrence S. Lerner, Ursula Goodenough, John Lynch, Martha Schwartz, and Richard Schwartz
NAEP review by Paul R. Gross

FOREWORD BY CHESTER E. FINN, JR., AND KATHLEEN PORTER-MAGEE

THOMAS B. FORDHAM INSTITUTE
ADVANCING EDUCATIONAL EXCELLENCE

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Foreword

By Chester E. Finn, Jr., and Kathleen Porter-Magee

Since *Sputnik* shot into orbit in 1957, Americans have considered science education to be vital to our national security and economic competitiveness. The impact of the Soviet satellite launch on American science classrooms was almost immediate. Shirley Malcolm, a leader in the field of science education (and presently head of education programs for the American Association for the Advancement of Science), was a young student in Alabama at the time. She described the swift and palpable shift in the way science was taught:

> **We stopped having throwaway science and started having real science…All of a sudden everybody was talking about it, and science was above the fold in the newspaper, and my teachers went to institutes and really got us all engaged. It was just a time of incredible intensity and attention to science.[1]**

The impact on public opinion was just as profound—and national concern over the quality of American science, and science education, has continued for the past half century. According to a 2011 survey, 74 percent of Americans think STEM (Science, Technology, Engineering, and Math) education is "very important." Only two percent say it's "not too important."[2]

Yet this strong conviction has not translated into strong science achievement. The 2009 National Assessment of Educational Progress (NAEP) found barely one-third of fourth graders in the United States at or above the "proficient" level in science, with those proportions slipping to 30 percent in eighth grade and a woeful 21 percent in twelfth grade.[3] Another recent study reported that just 30 percent of our high school graduates are prepared for college-level work in science.[4]

International comparison is even more disheartening. The most recent PISA assessment, released in December 2010, showed fifteen-year-olds in the United States ranking a mediocre twenty-third out of sixty-five countries. By contrast, youngsters in Shanghai ranked first, demonstrating both China's commitment to science education—and the various bounties that accompany it—and that nation's capacity to deliver on its educational aspirations.

Similarly, on the 2007 TIMSS science assessment, American eighth graders overall ranked eleventh out of forty-eight nations and were trounced not only by the likes of Singapore and Japan, but also by the Czech Republic, Hungary, and Slovenia.[5] Even more distressing, only 10 percent of American

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[1] Cornelia Dean, "When Science Suddenly Mattered, in Space and in Class," *New York Times*, September 25, 2007, http://www.nytimes.com/2007/09/25/science/space/25educ.html?pagewanted=all.

[2] Research!America, *Your Congress-Your Health: National Public Opinion Poll* (Alexandria, VA: Research!America, March 2011), http://www.yourcongressyourhealth.org/admin/Editor/assets/yourcongress2011.pdf.

[3] Institute of Education Sciences, *Science 2009: National Assessment of Educational Progress at Grades 4, 8, and 12* (Washington, D.C.: National Center for Education Statistics, January 2011), http://nces.ed.gov/nationsreportcard/pdf/main2009/2011451.pdf.

[4] ACT, Inc., *The Condition of College & Career Readiness* (Iowa City, IA: ACT, Inc., 2011), http://www.act.org/research/policymakers/cccr11/readiness1.html.

[5] Patrick Gonzalez, *Highlights from TIMSS 2007: Mathematics and Science Achievement of U.S. Fourth- and Eighth-Grade Students in an International Context* (Washington, D.C.: National Center for Education Statistics, September 2009), http://nces.ed.gov/pubs2009/2009001.pdf.

eighth graders scored at or above the TIMSS "advanced" level. By contrast, 32 percent of students in Singapore reached that level.

The evidence is indisputable—and should be alarming. While no one test can communicate the full picture of education achievement, if our students' performance on international assessments like TIMSS and PISA is any indication, the United States is doing little more than *talking* about the importance of getting science education right.

Why is this? How can it be that, for more than five decades, Americans have voiced so much concern about science education yet made so little progress in delivering it? There are, of course, multiple explanations, starting with the blunt fact that few states and communities have taken concrete action to build world-class science programs into their primary and secondary schools. Without such programs in place to deliver the goods, our Sputnik-induced anxieties remain fully justified some fifty-five years later.

A solid science education program begins by clearly establishing what well-educated youngsters need to learn about this multi-faceted domain of human knowledge. Here, the first crucial step is setting clear academic standards for the schools—standards that not only articulate the critical science content students need to learn, but that also properly sequence and prioritize that content. In the light of such standards, teachers at each grade level can clearly see where they should focus their time and attention to ensure that their pupils are on track toward college- and career-readiness. That doesn't mean it will happen, of course. As we at the Thomas B. Fordham Institute have repeatedly noted, standards alone cannot drive outstanding achievement. But they are a necessary starting point. They are the score for conductors, musicians, instrument makers, and more. They are the foundation upon which rigorous curricula and instructional materials and assessments are built. They are the template for preparing science teachers for our classrooms.

Fordham has a long-standing interest in science standards and a history of reviewing them with care and rigor. We published our first analysis of state science standards in 1998 and a follow-up review in 2005. Unfortunately, the findings from both evaluations were not good. In 1998, just thirty-six states had even set standards for science, and only thirteen of those earned grades from our reviewers in the A or B range. By 2005, though every state except Iowa had articulated K-12 science standards, the results were equally disheartening: just nineteen earned honors grades, and the overall average was barely a C.

Why So Different?

This variability in the quality of standards is as unacceptable as it is unnecessary. As one of us observed in our 1998 review:

> **If any subject has the same essentials everywhere, after all, it's science. I can think of no sound reason why what is expected of teachers and children in biology or chemistry should be different in Tennessee…than Indiana. Indeed, it should be approximately the same as what is expected in Singapore and Germany, too.[6]**

Science is not, of course, the only core subject where it makes no sense for young Americans to be held to different standards depending on where they live. That is why the Council of Chief State Schools Officers (CCSSO) and National Governors Association (NGA) came together in 2009 to build rigorous common standards for English language arts (ELA) and mathematics. These common standards aimed to articulate the knowledge and skills that all students need to master across grades K-12 if they are to succeed in college and career. The result of this effort was the 2010 "Common Core" standards for ELA and math. Notably, these standards are clearer and more rigorous than those in use in most states. Fordham's own analysis, comparing state ELA and math standards with the Common Core standards, concluded that, "out of 102 comparisons—fifty-one jurisdictions times two subjects—we found the Common Core clearly superior seventy-six times."[7]

Today, a similar push toward quality common standards is underway for science. Twenty-six states have teamed up with Achieve, Inc. to craft "Next Generation Science Standards" (NGSS). This group intends to do for science what the CCSSO and NGA did for ELA and math: create a set of clear, rigorous, and specific expectations that states will have the option to adopt as their own. Indeed, such a movement is long overdue.

Like the drafters of the Common Core standards, Achieve and its partners will look to national and international models as starting points for the development of the NGSS. Among those models is the *Framework for K-12 Science Education* released by the National Research Council (NRC) in July 2011. While not a set of standards, the NRC states that the *Framework* includes "the key scientific practices,

[6] Chester E. Finn, Jr., foreword to *State Science Standards 1998*, by Lawrence S. Lerner (Washington, D.C.: Thomas B. Fordham Institute, March 1998), http://www.edexcellence.net/publications/stsciencestnds.html.

[7] Sheila Byrd Carmichael, Gabrielle Martino, Kathleen Porter-Magee, and W. Stephen Wilson, *The State of State Standards—and the Common Core—in 2010* (Washington, D.C.: Thomas B. Fordham Institute, July 2010), http://www.edexcellence.net/publications/the-state-of-state.html.

concepts, and ideas that all students should learn by the time they complete high school" and that it is "intended as a guide for those who develop science education standards, those who design curricula and assessments, and others who work in K-12 science education."[8]

In August 2011, we asked the distinguished biologist (and veteran Fordham science reviewer) Paul R. Gross to evaluate the NRC *Framework*. Overall, he gave it a solid B-plus, and found that the document includes nearly all of content necessary for a rigorous K-12 science curriculum.[9] Dr. Gross did caution, however, that the *Framework* may have paid too much attention to engineering and technology, as well as to "science process" skills. And he warned that standards writers using this framework as a model will need to make difficult decisions about priorities that were not made by the *Framework* authors.

When those "common" standards for science are ready, we at the Thomas B. Fordham Institute will review and evaluate them. But we also want to help states now—for today's students can't wait for common science standards, and today's states are using academic standards of their own as the basis for what their schools will teach and their children will learn.

Hence it's time for a fresh review of existing state science standards. While forty-nine states and the District of Columbia had articulated science standards when we examined them in 2005, Iowa subsequently wrote its own standards and forty-two states and the District of Columbia have changed their standards during the ensuing years.

Our Approach

This report is part of a comprehensive series of fresh appraisals by Fordham of state, national, and international standards in all core content areas. Here we provide analyses of the K-12 science standards currently in place in all fifty states and the District of Columbia, as well as the assessment framework that undergirds the NAEP science assessment. These reviews should also help states gauge the comparative strengths and weaknesses of their standards vis-à-vis the forthcoming Next Generation Science Standards—and how they stack up today against the science education expectations that undergird NAEP.

Why Review NAEP?

The National Assessment of Education Progress (NAEP) is the most-often used barometer of student learning in science. Results from NAEP are used to compare student achievement across states and to judge states' student-proficiency levels. Because NAEP is so central to the conversation on state and national science achievement, we felt it was important to analyze the quality of its implicit standards—embodied in its assessment framework—to see how they compare with the quality of each state's standards.

For these reviews, we have enlisted the help of several veteran reviewers, all of them experts in their field. Lawrence Lerner joined us as lead author for this evaluation of state science standards. Dr. Lerner has played a role in all of our science reviews, dating back to 1998. This time he is joined by a team of experts: Ursula Goodenough, who evaluated life science; Richard Schwartz, who primarily reviewed chemistry and physical science; Martha Schwartz, who analyzed earth and space science; and John Lynch, who evaluated "science inquiry" standards.

In addition, Dr. Gross rejoined us to appraise the NAEP assessment framework for science.

Our experts employed new and improved content-specific criteria as well as the "common grading metric" that has been used for all of the reports in this cycle of Fordham standards reviews.[10] Application of those criteria and the common metric yields—for every state in every subject—a two-part score: a tally from zero to seven for "content and rigor," and a tally from zero to three for "clarity and specificity." These were combined such that each set of standards obtained a total number grade (up to ten), which was then converted to a letter grade (from A through F). (For more detail, see Appendix A: Methods, Criteria, and Grading Metric.)

What We Found

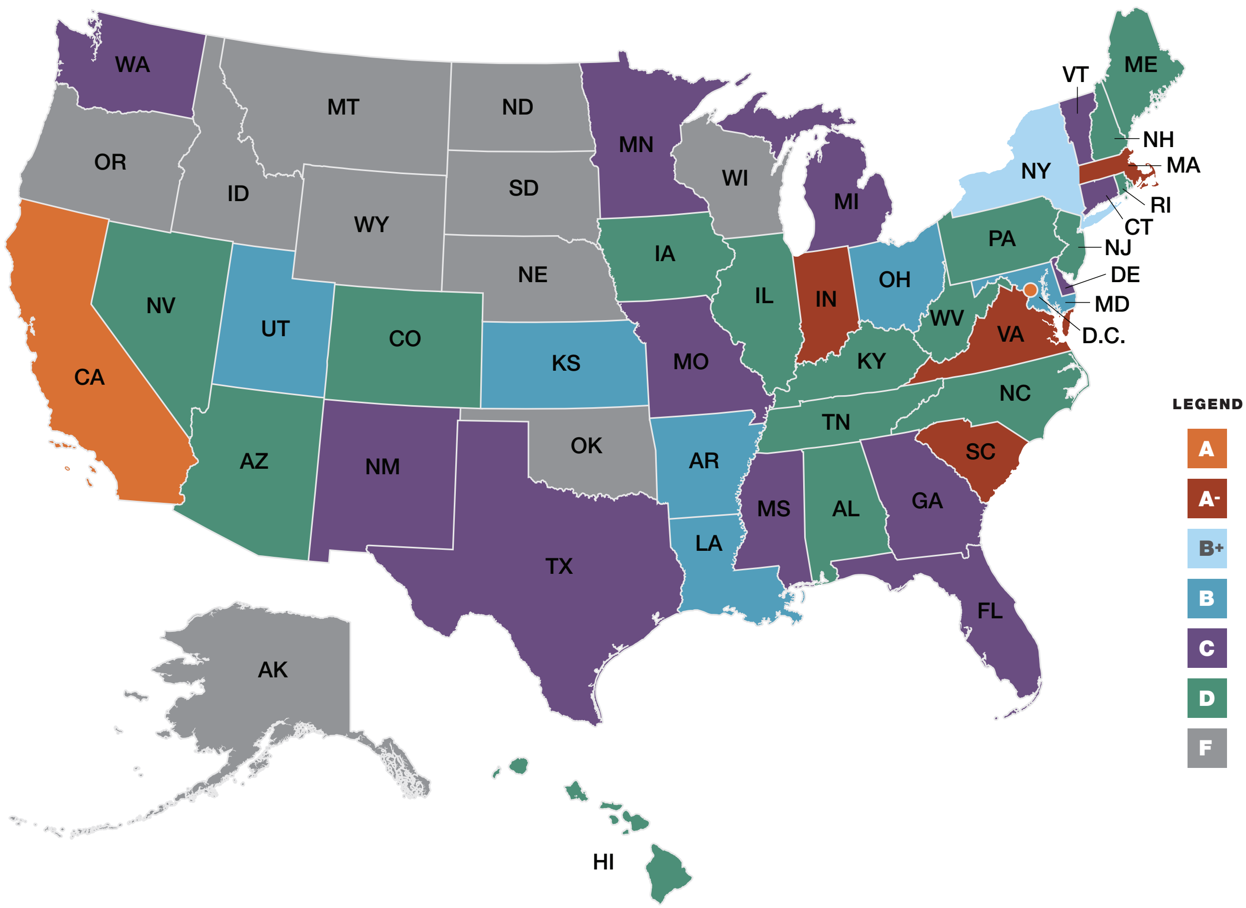
The results of this rigorous analysis paint a fresh—but still bleak—picture. A majority of the states' standards remain mediocre to awful. In fact, the average grade across *all* states is—once again—a thoroughly undistinguished C. (In fact, it's a

[8] National Research Council, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (Washington, D.C.: National Research Council, July 2011), http://www.nap.edu/catalog.php?record_id=13165.

[9] Paul R. Gross, *Review of the National Research Council's Framework for K-12 Science Education* (Washington, D.C.: Thomas B. Fordham Institute, October 2011), http://www.edexcellence.net/publications/review-of-the-nrc-framework-for-k12-science-education.html.

[10] To read our 2010 review of state ELA and math standards and the Common Core, see http://www.edexcellence.net/publications/the-state-of-state.html. For our 2011 analysis of state U.S. History standards, see http://www.edexcellence.net/publications/the-state-of-state-us.html.

State Science Standards Grades, 2012



low C.) In twenty-six jurisdictions, the science standards earn a D or below. Yet this very weakness in what states expect of their schools, teachers, and students in science suggests that a purposeful focus on improving—or replacing—today's standards could be a key part of a comprehensive effort to boost science performance.

Two jurisdictions—California and the District of Columbia—have standards strong enough to earn straight As from our reviewers. Four other states—Indiana, Massachusetts, South Carolina, and Virginia—earn A-minuses, as does the NAEP assessment framework. And seven states earn grades in the B range. But this also means that just thirteen jurisdictions—barely 25 percent, and fewer than in 2005—earn a B or better for setting appropriately clear, rigorous, and specific standards.

Of course, as Dr. Lerner noted in 1998:

> **When it comes to academic standards…even a "B" ought not be deemed satisfactory. In a properly organized education system, standards drive everything else. If they are only "pretty good," then "pretty good" is the best the system is apt to produce by way of student learning. No state should be satisfied with such a result. Hence, no state should be satisfied with less than world-class standards in a core academic subject such as science.**

States looking to improve their standards, however, need not start from scratch, or even wait for the NGSS. They can look to places like California and the District of Columbia, and also to the NAEP assessment framework, for models of excellence.

Let us repeat that even the finest of standards alone will never yield outstanding academic achievement. Several states with exemplary science standards still aren't serious about setting high proficiency bars on their assessments. Others don't hold students (or their teachers) properly accountable for learning (or successfully imparting) important content. And still others haven't provided (or directed teachers to) the curricular and instructional resources that teachers need to drive achievement. But,

Table 1. 2005 and 2012 Grades in Alphabetical Order

Jurisdiction	2005 Grade	2012 Grade	Jurisdiction	2005 Grade	2012 Grade
Alabama	F	D	Montana	F	F
Alaska	F	F	Nebraska	F	F
Arizona	B	D	Nevada	D	D
Arkansas	D	B	New Hampshire	F	D
California	A	A	New Jersey	B	D
Colorado	B	D	New Mexico	A	C
Connecticut	C	C	New York	A	B+
Delaware	C	C	North Carolina	B	D
District of Columbia	C	A	North Dakota	D	F
Florida	F	C	Ohio	B	B
Georgia	B	C	Oklahoma	F	F
Hawaii	F	D	Oregon	F	F
Idaho	F	F	Pennsylvania	C	D
Illinois	B	D	Rhode Island	C	D
Indiana	A	A-	South Carolina	A	A-
Iowa	N/A	D	South Dakota	D	F
Kansas	F	B	Tennessee	B	D
Kentucky	D	D	Texas	F	C
Louisiana	B	B	Utah	C	B
Maine	D	D	Vermont	C	C
Maryland	B	B	Virginia	A	A-
Massachusetts	A	A-	Washington	C	C
Michigan	D	C	West Virginia	B	D
Minnesota	B	C	Wisconsin	F	F
Mississippi	F	C	Wyoming	F	F
Missouri	C	C			

while standards alone won't drive achievement, they are an important place to start.

Changes since 2005

Of the forty-four jurisdictions that have revised or replaced their science standards since our 2005 analysis, eleven have shown some improvement, and some of that improvement has been dramatic (see Table 1). Kansas, for example, moved from an F to a B and Arkansas moved from a D to a B. The District of Columbia rose from a mediocre C in our last analysis to a best-in-class A this time.

By contrast, sixteen states managed to make their standards *worse* since 2005. In fact, five of them—Colorado, New Jersey, North Carolina, Tennessee, and West Virginia—dropped from Bs to Ds.

On balance, the combination of improvements and worsenings had little impact on our national average. In both 2005 and 2012, the average grade for state science standards was a minimal C.[11]

[11] Note, however, that our criteria have changed since 2005. Therefore, changes in a state's grade could be due to changes in the quality of the standards, changes in our criteria, or both. For more information on our grading metric, see Appendix A.

Acknowledgments

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We also thank the many individuals who made this endeavor possible. First and foremost, we are deeply grateful to our content-area experts and report authors, Lawrence Lerner, Richard Schwartz, Martha Schwartz, Ursula Goodenough, and John Lynch. We are also grateful to Lawrence Lerner and Adam Marcus for helping to cobble together the patchwork of reviews into a single, clean product. And once again, we thank Paul Gross, who helped shape the direction of the project and provided wisdom and guidance throughout, in addition to conducting the NAEP review.

At the Fordham end, special thanks goes first to Amber Winkler, Fordham's vice president for research, who provided ongoing guidance and support from the project's inception, and to Daniela Fairchild, who helped manage the project and steer it toward the finish line. We are also grateful to our team of interns—Alicia Goldberg, Josh Pierson, Laura Johnson, and Michael Ishimoto—for their help researching the standards, confirming standards documents, and reviewing the final report.

Special thanks go as well to the Fordham production team—Janie Scull, Joe Portnoy, and Tyson Eberhardt—for the work they did to ensure the final report was properly edited, published, and disseminated. We are grateful to Shannon Last and Alton Creative, not just for their expert copyediting and layout work (respectively), but also for their hard work and patience as we moved this report through production. Finally, we thank Sarah Samaroo for producing an epic cover illustration.

Introduction

This report examines K-12 science standards for fifty states and the District of Columbia, as well as the science assessment framework of the National Assessment of Educational Progress (NAEP). Our aim is to evaluate them for their intrinsic clarity, completeness, and scientific correctness. We have not investigated whether they are being properly assessed with state tests or effectively implemented in the schools, or whether they are driving improvements in student achievement.

That said, setting clear, thorough, and rigorous standards is critical. They are the foundation upon which a state's system of assessment, instruction, and accountability rests.

2012 Analysis: Where State Standards Go Wrong

Our earlier evaluations, as well as those evaluations conducted by others, have made it clear that too many state science standards are mediocre to poor. In particular, there are four areas where they most frequently fail to measure up.

Problem 1: An Undermining of Evolution

"Nothing in biology makes sense except in the light of evolution." So wrote famed biologist Theodosius Dobzhansky in 1973.[12] And so it is today. Yet controversy continues to envelop the teaching of evolution in American schools. One wonders, indeed, how much progress we've made in this realm since the Scopes trial in 1925. Six years ago, our science reviewers noted that:

> **The attack on evolution is unabated [since 2000], and Darwin's critics have evolved a more-subtle, more dangerous approach. A decade ago, the anti-evolution movement…argued vigorously for explicit teaching of the evidence for intelligent design. …The claim now is that evidence against "Darwinism" exists, that curriculum-makers should include it as an exercise in critical thinking, and that "freedom of speech" or "fairness" requires that they do so. The hidden agenda is to introduce doubt—any possible doubt—about evolution at the critical early stage of introduction to the relevant science.[13]**

While many states are handling evolution better today than in the past, anti-evolution pressures continue to threaten state science standards. In June 2008, for example, Louisiana passed its infamous Science Education Act, ostensibly an "academic freedoms act" meant to give teachers and students legal cover to debate the merits and veracity of scientific theories. In practice, the measure pushes a pro-creationist agenda—and gives cover to those looking to teach intelligent design creationism. Though the act is a free-standing statute with no direct link to the Pelican State's academic standards, it does damage by allowing for the introduction of creationist teaching supplements—thereby affecting classroom instruction without explicitly altering the state's standards.[14]

Louisiana is not the only state that has tried to undermine the teaching of evolution through legislation. In 2011 alone, eight

[12] Theodosius Dobzhansky, "Nothing in Biology Makes Sense Except in the Light of Evolution," *The American Biology Teacher* 35 (1973): 125-129, http://people.delphiforums.com/lordorman/Dobzhansky.pdf.

[13] Paul R. Gross, *The State of State Science Standards 2005* (Washington, D.C.: Thomas B. Fordham Institute, December 2005), http://www.edexcellence.net/publications/index.jsp?issuestopics=standards-testing-accountability&page=8.

[14] For details, see *Bulletin 741—Louisiana Handbook for School Administrators*, published by the Louisiana Board of Elementary and Secondary Education at http://www.doa.louisiana.gov/osr/lac/28v115/28v115.doc. Section 2304 stipulates how the Science Education Act is to be administered by school administrators and teachers at the parish and local levels.

anti-evolution bills were introduced in six state legislatures. (Thankfully, none made it into law.) And two similar bills were pre-filed in New Hampshire for the 2012 legislative session,[15] as well as one in Indiana.[16]

Of course, most anti-evolution efforts are aimed more directly at the standards themselves. And these tactics are far more subtle than they once were. Missouri, for example, has asterisked all "controversial" evolution content in the standards and relegated it to a voluntary curriculum that will not be assessed. (Sadly, this marks a step back from that state's coverage of evolution in 2005.) And Maryland includes evolution content in its Kindergarten through eighth-grade standards but explicitly excludes crucial points from its state assessment.

Other states have undermined the teaching of evolution by singling it out as somehow not quite as "scientific" as other concepts of similar breadth. A common technique—used to a greater or lesser extent by Colorado, Missouri, Montana, and West Virginia—is to direct students to study its "strengths and weaknesses."

Far too often, important evolution content is included, but minimally. Some states mention evolution just once in their standards and never revisit it. Others—including Indiana, Iowa, Kansas, Kentucky, Michigan, and Nebraska—unnecessarily delay it until high school.

Even some of the nation's best standards subtly undermine the teaching of evolution. In California, for example, students are told to "understand science, not necessarily [to] accept everything taught." In New York, students learn that "according to many scientists, biological evolution occurs through natural selection." (This is not according to "many" but, in fact, *all* true scientists.)

Finally, conspicuously missing from the vast majority of states' standards is mention of *human* evolution—implying that elements of biological evolution don't pertain to human life. This marks a subtle but important victory for creationists: Even states with thorough and appropriate coverage of evolution (e.g., Massachusetts, Utah, and Washington) shy away from linking the controversial term with ourselves. Only four states—Florida, New Hampshire, Iowa, and Rhode Island—openly embrace human evolution in their current science standards. (Pennsylvania, which referenced human evolution in its previous standards, has omitted it from the more recent version.)

Problem 2: A Propensity to be Vague

Educators should not be confronted with standards that are so vague as to be meaningless—and yet, based on our current analysis, that is precisely what many states have imposed on their teachers. In fact, only seven states had standards clear enough to earn them full-credit scores of three out of three points for clarity and specificity. Twenty-eight earned a one or zero out of three.

A middle school teacher in New Hampshire, for example, will come face to face with the following: "Identify energy as a property of many substances." Pennsylvania offers the equally baffling "Explain the chemistry of metabolism." Such empty statements can do little to inform curriculum development or instruction, and give no guidance to assessment developers.

Similarly, New Jersey students are asked to:

> **Demonstrate understanding of the interrelationships among fundamental concepts in the physical, life, and Earth systems sciences. (grade 4)**
>
> **Use outcomes of investigations to build and refine questions, models, and explanations. (grade 4)**

These expectations contain virtually no specific content; it's impossible to determine what students should actually know or be able to do. To our dismay, similarly vague and meaningless statements are common across far too many state standards.

A few, however, have crafted clear and specific standards that could easily form the basis of a rigorous K-12 science curriculum. For instance, the California standards explain:

[15] House Bill 1148, introduced by Jerry Bergevin (R-District 17), would charge the state board of education to "[r]equire evolution to be taught in the public schools of this state as a theory, including the theorists' political and ideological viewpoints and their position on the concept of atheism." House Bill 1457, introduced by Gary Hopper (R-District 7) and John Burt (R-District 7), would charge the state board of education to "[r]equire science teachers to instruct pupils that proper scientific inquire [*sic*] results from not committing to any one theory or hypothesis, no matter how firmly it appears to be established, and that scientific and technological innovations based on new evidence can challenge accepted scientific theories or modes." Although HB 1457, as drafted, is silent about intelligent design, Hopper's initial request was to have a bill drafted that would require "instruction in intelligent design in the public schools." Both bills were referred to the House Education Committee; HB 1148 is scheduled for hearing on February 9, 2012, and HB 1457 is scheduled for hearing on February 14, 2012.

[16] Senate Bill 89, pre-filed in the Indiana Senate and referred to the Committee on Education and Career Development, would, if enacted, amend the Indiana Code to provide that "[t]he governing body of a school corporation may require the teaching of various theories concerning the origin of life, including creation science, within the school corporation." The sponsor of the bill is Dennis Kruse (R-District 14), who chairs the Senate Committee on Education and Career Development.

Electricity and magnetism are related effects that have many useful applications in everyday life. As a basis for understanding this concept:

- ***Students know*** **how to design and build simple series and parallel circuits by using components such as wires, batteries, and bulbs.**
- ***Students know*** **how to build a simple compass and use it to detect magnetic effects, including Earth's magnetic field.**
- ***Students know*** **electric currents produce magnetic fields and know how to build a simple electromagnet.**
- ***Students know*** **the role of electromagnets in the construction of electric motors, electric generators, and simple devices, such as doorbells and earphones.**
- ***Students know*** **electrically charged objects attract or repel each other.**
- ***Students know*** **that magnets have two poles (north and south) and that like poles repel each other while unlike poles attract each other.**
- ***Students know*** **electrical energy can be converted to heat, light, and motion. (grade 4)**

This standard leaves no question as to what, precisely, students should know or be able to do.

Alas, such cogent and unambiguous writing is distressingly rare.

Problem 3: Poor Integration of Scientific Inquiry

For at least the past fifteen years—possibly even longer—science educators, curriculum developers, and standards writers have focused greater and greater attention on "inquiry-based learning." In practice, this means helping students learn scientific content through discovery, as opposed to through direct instruction of specific content. Indeed, the National Science Teachers Association (NSTA) recommends that all K-16 teachers "embrace scientific inquiry" and that they "make it the centerpiece of the science classroom."[17]

Of course, inquiry has an important role in science classrooms. Students should learn important process and methodology skills. They should be introduced to important concepts like theory and hypothesis early in their K-12 education, and they should learn about the history and evolution of science.

Unfortunately, in too many states, the inquiry standards are vague to the point of uselessness. In Idaho, for instance, students are merely asked to "make observations" or to "use cooperation and interaction skills." And Iowa schoolchildren are directed to:

> **Make appropriate personal/lifestyle/technology choices, evaluate, observe, discuss/debate, recognize interactions and interdependencies at all levels, explain, describe environmental effects of public policy, choose appropriate course(s) of action.**

Such statements are devoid of any teachable content and leave teachers with no guidance as to how they can incorporate genuine scientific inquiry skills into their instruction.

Furthermore, inquiry standards can only enhance student learning if they are meaningfully linked to content. Unfortunately, too many states treat inquiry as an afterthought or add-on. In Michigan, for example, a stand-alone inquiry standard asks first graders to "make careful and purposeful observations in order to raise questions, investigate, and make meaning of their findings." Such expectations—which are distressingly common—present lofty goals that are hollow when not integrated with content.

Another common problem with state inquiry standards is their failure to address the history of science properly. Far too often, the history of science is missing entirely. And of the states that do include it, too many include overly broad directives that lack any real substance. In Maryland, for instance, students are told only that science has been done by "different kinds of people, in different cultures, at different times," an inane statement that gives teachers no direction as to what important scientific history students should learn.

Problem 4: Where Did All the Numbers Go?

Mathematics is integral to science. Yet few states make the link between math and science clear—and many seem to go to great lengths to avoid mathematical formulae and equations altogether. The result is usually a clumsy mishmash of poor writing that could much more easily and clearly be expressed in numbers.

It makes sense, of course, to focus science education on qualitative matters in the earlier grades, since students have not yet acquired a broad mathematical background and there is still plenty of qualitative material they need to learn. For the fourth-grade student, it is fine to define energy as "what makes things happen," as many states do in one way or another. But once students have learned some algebra—it doesn't need to be a lot—it is important to make

[17] National Science Teachers Association, "NSTA Position Statement: Scientific Inquiry," October 2004, http://www.nsta.org/about/positions/inquiry.aspx?print=true.

things quantitative, as in this standard from the District of Columbia:

> **Recognize that when a net force, *F*, acts through a distance, Δx, on an object of mass, *m*, which is initially at rest, work, $W = F\Delta x$, is done on the object; the object acquires a velocity, *v*, and a kinetic energy, $K = \frac{1}{2} mv^2 = W = F\Delta x$. (high school physics)**

Only then can the student understand such vital principles as the law of conservation of energy, because that understanding depends on comparing two numbers and showing that they are the same.

Unfortunately, few states take the approach of progressing from qualitative to quantitative insights. Far more typical is this passage from Illinois:

> **Understand that energy, defined somewhat circularly, is 'the ability to change matter,' or 'the ability to do work.' Understand that energy is defined by the way it is measured or quantified. Understand the difference between potential and kinetic energy. (grade 11)**

Such a limited definition of energy cannot possibly prepare students for college-level work.

While physics is the most mathematical of the sciences, a genuine understanding of chemistry also depends on the ability to perform quantitative operations. Such vital concepts as equilibrium, ion concentration, and many others are entirely dependent upon that ability. Nor can one acquire a keen insight into the other high school sciences without some exposure to quantitative methods.

• • •

Every state has the resources to produce excellent K-12 science standards. It is our hope that a closer approach to this ideal appears in the not-too-distant future, as states independently pen much improved standards, adopt (or crib from) existing excellent ones, or embrace more or less nationwide models that have been prepared and scrutinized by recognized experts.

SCIENCE

Alabama

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	3/7	4/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**2.7**
Scientific Inquiry & Methodology	2
Physical Science	3
Physics	1
Chemistry	3
Earth & Space Science	4
Life Science	3
Clarity & Specificity	**1.4**

Average numerical evaluations

Overview

Alabama's science standards generally fail to outline the essential science content teachers need to teach—and students need to learn. Although not every area is bereft of useful material, the treatment of concepts often is haphazard, incomplete, puzzling, and at times incorrect. The result is a hash from which frustrated educators will be hard-pressed to extract an effective curriculum.

Organization of the Standards

The Alabama science standards are presented in four documents, one each for the grade bands covering K-2, 3-5, 6-8, and high school. For grades K-5, grade-specific standards are divided into three familiar strands: physical science, life science, and earth and space science. For grades 6-8, grade-specific standards are focused on a single content area each year: Sixth grade focuses on earth and space science, seventh grade on life science, and eighth grade on physical science (covering chemistry and physics). At the high school level, standards are presented for four core courses (physical science, biology, chemistry, and physics) as well as for ten discrete electives, including botany, forensic science, and zoology.

For each grade and course, individual standards include three component parts. First, the state presents content standards. Under the content standards is a series of bullets, which explain "content that is related to the standards and required for instruction." Examples are provided to clarify either content standards or bullets.

Content and Rigor

Across the board, Alabama's standards are mediocre to poor. Large swaths of important information are missing, and what is present often receives cursory treatment. A penchant for bulleted lists does not serve the document well. Equally problematic, the material is occasionally far too challenging for the specified grade level—particularly considering the lack of adequate development that pervades the standards.

Scientific Inquiry and Methodology

The standards explain that "process and application skills" should be "embedded throughout the content areas and applied through the use of inquiry." Unfortunately,

Document(s) Reviewed[1]

- *Alabama Course of Study: Science*. 2005. Accessed from: http://www.alsde.edu/html/sections/documents.asp?section=54&sort=4&footer=sections

[1] Fordham's 2005 evaluation also reviewed Alabama's 2005 content-standards document. Since 2005, we have updated and improved the evaluation criteria used to judge the standards. (See Appendix A for a complete explanation of the criteria used in this review.) Through this new lens, Alabama's science grade rose from an F to a D. The complete 2005 review can be found here: http://www.edexcellence.net/publicationsissues/publications/sosscience05.html.

due in large part to the standards' brevity and subsequent vagueness, there is little guidance about how, exactly, these skills should be embedded into the content. For instance, the standards explain that analyzing data involves "using collected data to accept or reject hypotheses," a woefully inadequate description of the importance of data to scientific inquiry. This lack of specificity permeates the Alabama inquiry standards. The state's guidelines on cultural diversity in science, for example, state that "integration of culturally relevant biographical sketches of male and female scientists from a variety of ethnic backgrounds...should be incorporated into scientific topics." Sure, but no guidance is given as to which scientists should be studied.

Worse, what little guidance does exist is often rife with errors. For instance, one standard claims that "formulating hypotheses" (an "advanced" skill) comes down to "making predictions of future events based on manipulation of variables." No, it does not.

Physical Science

Physical science is covered in Kindergarten through fifth grade, as well as in eighth grade (which is solely devoted to the subject) and in a high school physical science course. In general, the eighth-grade coverage is spotty. Much content is present (at least in passing), including the atomic structure, chemical reactions, kinetic theory, mechanics, energy, hydrostatics, and waves. Yet many topics—such as gravitation, thermodynamics, optics, electromagnetism, and organic chemistry—are missing, and Alabama often fails to provide adequate detail for those topics that are covered. For instance, balancing chemical equations is introduced in eighth grade, as is chemical bonding. However, only ionic and covalent bonds are mentioned. As another example:

> **[Describe] acids and bases based on their hydrogen ion concentration. (grade 8)**

Much important content is missing here: What is meant by "concentration"? How is concentration measured? What are the properties, common names, and formulas of acids and bases? How does one use the pH scale, litmus, and other acid/base indicators? What is the mechanism of neutralization reactions?

This same situation holds true for high school physical science. Here, Alabama boasts some rigorous content (the implicit reference to Ampère's and Faraday's laws, for example), while simultaneously skipping numerous important topics. Optics, acoustics, hydrostatics and hydrodynamics, and alternating currents (except for a passing, cryptic mention of induction) are all absent.

And the last standard in the high school physical science section—"Identify metric units for mass, distance, time, temperature, velocity, acceleration, density, force, energy, and power"—reads like an odd afterthought, when it ought to be a central point.

High School Physics

Admirably, the high school physics course specifies Algebra II with trigonometry as a prerequisite. But this hopeful sign only leads to disappointment. Kinematics is covered briefly and somewhat by implication, but all of dynamics is passed off and folded into other areas, as with the following:

> **Describe quantitative relationships for velocity, acceleration, force, work, power, potential energy, and kinetic energy. (high school physics)**

This does not bode well for real application of the laudable mathematical prerequisites.

What's more, the content that is present often lacks sufficient depth of focus, as is the case with thermodynamics, waves, optics, electromagnetism, and practical electricity.

The standards are further marred by inappropriate sequencing. For example, concepts of energy are presented before dynamics—though the former must be derived from the latter.

The wonderful, mysterious word "entropy" is introduced with no prior mention of any of the laws of thermodynamics on which the concept is based. Everything is condensed into the illogical statement, "Explain the concept of entropy as it relates to heating and cooling, using the laws of thermodynamics."

Likewise, the central quantum mechanical concept of wave-particle duality is inexplicably jammed into the sequence of statements concerning classical waves, and the student is somehow expected to "demonstrate" the phenomenon.

High School Chemistry

As with the other disciplines, Alabama's chemistry standards suffer from vagueness and insufficient depth of coverage. For example, after appearing in the eighth-grade standards, chemical bonding is not mentioned again, except for this rather broad directive: "[Predict] ionic and covalent bond types and products given known reactants." And the entire topic of acid/base theory is summed up in only one bulleted item: "[Describe] acids and bases in terms of strength, concentration, pH, and neutralization reactions." The important concepts are there, but they need to be fleshed out.

Oddly, even as some basic concepts are omitted, advanced ones are included. In the nuclear chemistry standards, we see the following:

> **[Identify] atomic and subatomic particles, including mesons, quarks, tachyons, and baryons. (high school chemistry)**

The mention of tachyons (hypothetical particles whose *minimum* speed is the speed of light) is peculiar, since their existence is entirely speculative, while such significant particles as leptons (including electrons) and neutrinos are not mentioned at all. (What's more, the particles that *are* mentioned have more to do with modern physics than with chemistry.)

Earth and Space Science

The authors of the Alabama standards have made an effort to provide reasonable earth science content. Unfortunately, given the terseness of the state's standards (all sixth-grade content is explained in one-and-a-half pages, for example), much critical context and necessary explanation is missing. Take this sixth-grade standard, in which students are asked to:

> **Explain the plate tectonic theory.**
>
> > **Example: using terminology such as continental drift, seafloor spreading, lava, magma, eruption, epicenter, focus, seismic wave, and subduction zone**
>
> - **Describing types of volcanoes and faults**
> - **Determining energy release through seismographic data**
>
> > **Example: using data from the Mercalli scale and the Richter scale. (grade 6)**

This short excerpt contains a laundry list of vocabulary. The terms covered could act as a skeleton of strong state standards, but their required depth of study is a mystery. As an example, consider seismic waves. Are students merely supposed to know that they cause ground shaking? Or are they to describe body waves—whether primary (P) or secondary (S)—and surface waves? Or, better still, are they to show how P and S waves may be used to locate an earthquake's focus and epicenter (two other terms on the list)? And so it goes: good ideas not developed quite enough. The peaks and valleys of this standard are representative of the standards as a whole.

Still, there are some brighter spots where the content is spelled out carefully, as in the third-grade material on minerals:

> **[Classify] rocks and minerals by characteristics, including streak, color, hardness, magnetism, luster, and texture. (grade 3)**

This misses the mark just a little—rock classification is done a bit differently than mineral classification. The Alabama high school geology elective covers rocks nicely as well, though the state's high school earth and space science standards (which appear only in elective courses) suffer from the same deficit as their elementary and middle school counterparts: large chunks of loosely related content, which *could* outline an excellent course, whiz by in single statements.

Life Science

Alabama's life science standards start off on fairly firm footing—cells and tissues, photosynthesis, and plant and animal species are all well handled. In fourth grade, for example, students are to:

> **[Classify] common organisms into kingdoms, including Animalia, Plantae, Protista, Fungi, Archaebacteria, and Eubacteria. (grade 4)**

There are some *intimations* of evolution in the early grades, as in the following:

> **Identify characteristics of animals, including behavior, size, and body covering.**
>
> - **Comparing existing animals to extinct animals**
>
> > **Examples: iguana to stegosaurus, elephant to wooly mammoth. (grade 2)**
>
> **Describe evidence of species variation due to climate, changing landforms, interspecies interaction, and genetic mutation.**
>
> > **Examples: fossil records over geologic time, rapid bacterial mutations due to environmental pressures. (grade 7)**

At the high school level, biology is mostly good and includes some biochemistry and lots of genetics and environmental material. The high school course electives—genetics, botany, and human physiology—are also substantive. That said, there is one glaring deficit with the Alabama biology standards. Evolution, which should be a front-and-center feature of genetics, is all but absent.

Alabama is clearly frightened by the "E-word"—a phobia from which most other states have recovered. The term "evolution" occurs exactly once in the basic biology course, once more in the genetics elective course, not at all in any of the other seven life science electives, and (despite those intimations) never prior to high school. Perhaps this is not surprising, given that the Alabama Department of Education officially considers creationism, an explicitly religious and non-scientific position, to be a form of evolution.[2]

The high school biology course has only this to say about evolution:

> **Describe protective adaptations of animals, including mimicry, camouflage, beak type, migration, and hibernation.**
>
> - **Identifying ways in which the theory of evolution explains the nature and diversity of organisms**
> - **Describing natural selection, survival of the fittest, geographic isolation, and fossil record. (high school biology)**

The odd implication here is that evolution and natural selection are sub-categories of the listed adaptations, rather than the center of the entire study. What are otherwise reasonable standards are marred by this flagrant omission of this central tenet of the life sciences.

With but a few bright spots in individual categories, Alabama's science standards earn a lamentable three out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

Some of Alabama's standards are presented clearly, particularly those for life science. Where the Yellowhammer State stumbles is in its specificity. The content, provided in list form, is often skimpy and lacks the detail needed to guide instruction. In high school physical science, for example, students are asked to "explain the relationship between electricity and magnetism." That is a too-quick once-over for a topic that, at a minimum, requires inquiry into Ampère's law and Faraday's law. Such nebulous standards are especially common with some of the more complex science topics—such as deep time—making it even less likely that students will learn the essential content they need.

Furthermore, careless writing abounds, resulting in some standards that are simply wrong:

> **[Determine] the resultant of collinear forces acting on a body**
>
> > **Example: solving problems involving the effect of a tailwind or headwind on an airplane. (high school physical science)**

While the example does involve the addition of two collinear *vectors*, they are certainly not *forces*!

Taken together, these issues lower Alabama's clarity and specificity score to a one out of three. (See Appendix A: Methods, Criteria, and Grading Metric.)

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[2] Michael Sibley, director of communications for the Alabama Department of Education, recently explained the state's position, saying: "The Alabama Course of Study deals with Theories of Evolution...Creationism is one of those theories." See Joshua Rhett Miller, "Claims that Bibles Were Distributed to Alabama Elementary Students Are Inaccurate, School Superintendent Says," *Foxnews.com*, March 24, 2011, http://www.foxnews.com/us/2011/03/24/alabama-superintendent-denies-claims-bibles-distributed-class/#ixzz1IVCPjXe0.

SCIENCE

Alaska

GRADE	SCORES		TOTAL SCORE
F	Content and Rigor	1/7	2/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**1.2**
Scientific Inquiry & Methodology	2
Physical Science	2
Physics	0
Chemistry	0
Earth & Space Science	1
Life Science	2
Clarity & Specificity	**1.1**

Average numerical evaluations

Document(s) Reviewed

- *Alaska Content Standards: Science; Fourth Edition*. Revised March 2006. Accessed from: http://www.eed.state.ak.us/contentstandards/Science.html
- *Alaska Science Performance Standards (Grade-Level Expectations)*. 2005. Accessed from: http://www.eed.state.ak.us/tls/assessment/GLEHome.html

Overview

When Fordham first looked at Alaska's science standards more than ten years ago, the entire document was three pages long. It contained so little information that it could not be reviewed. Although the current iteration is bulkier, the standards still comprise just twenty-seven pages for all grades, three through eleven. (Alaska provides no science standards for Kindergarten through second grade or twelfth grade.) They are thin ice, indeed, for curriculum developers, test writers, parents, or teachers.

Organization of the Standards

The Alaska science content standards—brief as they are—are divided into seven strands: science as inquiry and process; concepts of physical science; concepts of life science; concepts of earth science; science and technology; culture, social, personal perspectives, and science; and the history and nature of science. For each strand, the state provides three or four broad standards meant to span all grades. For example, in the "concepts of life science" strand, a student who meets the content standard should "develop an understanding of the structure, function, behavior, development, life cycles, and diversity of living organisms."

A second document presenting performance standards further articulates the content standards. It provides grade-level expectations for each of the broad content standards for all grades, 3-11.

Content and Rigor

Between what is missing and what is shortchanged, it is hard to consider the Alaska document a set of real standards at all. Indeed, the state makes no provision for high school biology, chemistry, or physics, leaving an enormous body of essential content completely untouched.

Scientific Inquiry and Methodology

Four of Alaska's seven strands (described above) address scientific inquiry and methodology: science as inquiry and process; science and technology; cultural, social, personal perspectives, and science; and history and nature of science. All but the last suffer from an over-eagerness to give voice to "different ways of thinking" rather than to outline specific content that students should master. For instance, in the "cultural, social, personal perspectives" strand, students are to "develop an understanding that some individuals...use other beliefs and methods in addition to scientific methods to describe the world" and to "develop an understanding of the importance of recording and validating cultural knowledge." While these are admirable goals, they are not central to an education in the sciences. Indeed, there is much mention of "local knowledge" and how it "correlates" with the science standards. In early grades, students are asked to explore "local or traditional stories," explain a natural event, connect these stories to observations of nature, and identify "multiple explanations (e.g., oral traditions, folklore, scientific theory) of everyday events." Again, although exploring cultural heritage is a valuable and necessary part of education, it distracts from the matter at hand—education in scientific practice and content.

Incoherence abounds. In fourth grade, students are expected to support "their ideas with observations and peer review"; how the latter is to function is left unstated. In eleventh grade, students should be able to "describe the importance of logical arguments (i.e., thought experiments by Einstein, Hawking, Newton)." But there is scant evidence that the students have been given the opportunity to acquire the scientific background without which such description is empty.

Physical Science/High School Physics/High School Chemistry

The flaws in Alaska's treatment of physical science are impressive. The sole mention of electrical circuits, in ninth grade, is this: "The student demonstrates an understanding of how energy can be transformed, transferred, and conserved by...recognizing simple electrical circuits." But at least the phrase appears. A reader would search in vain for other critical terms: acids and bases, atomic number and atomic mass, formulas, chemical equations, isotopes.

The physical science category also is rife with outright errors. In the fifth-grade expectations, for example, students should be able to classify "the changes (i.e., heat, light, sound, and motion) that electrical energy undergoes in common household appliances (i.e., toaster, blender, radio, light bulb, heater)." That's inaccurate (and poorly written). Heat, light, sound, and motion are not "changes."

Similarly, students are asked first to recognize (in third grade) and then to explain (in fourth grade) how "temperature changes cause changes in phases of substances (e.g., ice changing to liquid water and liquid water to water vapor." But that's wrong. Heat, not temperature, causes phase changes; temperature remains constant during a phase change.

Earth and Space Science

The Alaska standards for earth and space science are woefully inadequate. In a state where nature is spectacular—gorgeous glaciers, active volcanoes, history of a great earthquake, mountains, active subduction, beautiful rocks and minerals—the standards provide no understanding or appreciation of it, with the exception of a mention of the aurora. For instance, despite the fact that volcanic eruptions and earthquakes are a real hazard in the state, they are only mentioned twice—once in sixth grade and once in seventh. And even then, the coverage is far too broad and ignores the workings of these important phenomena. Students are asked only to describe "how the surface can change rapidly as a result of geological activities (i.e., earthquakes, tsunamis, volcanoes, floods, landslides, avalanches)" in sixth grade and to describe "how the movement of tectonic plates results in both slow changes (e.g., formation of mountains, ocean floors, and basins) and short-term events (e.g., volcanic eruptions, seismic waves, and earthquakes) on the surface" in seventh grade.

The coverage of other topics is equally superficial or nonexistent. The word "mineral" appears only once in the entire document, and it is before the word "rights" in eleventh grade. The rock cycle is mentioned in several grades, but only sedimentary processes receive any detailed coverage. Stars are mentioned in a number of contexts, but not as organization of matter, and galaxies are missing entirely.

Weather is reasonably well covered. In third grade, students are asked to demonstrate "an understanding of cycles influenced by energy from the sun and by Earth's position and motion in our solar system by...using recorded weather patterns (e.g., temperature, cloud cover, or precipitation)." In seventh grade they are asked to describe "the weather using accepted meteorological terms (e.g., pressure systems, fronts, precipitation)." Climate is also covered adequately, if uninspiringly, in high school.

Life Science

Across all grades, the Alaska standards contain little useful content in biology—less than what is conveyed in most states' middle school standards alone. For example, high school students are to "[relate] the structure of DNA to characteristics of an organism" (grade 11); to "[explain] that cells have specialized structures in which chemical reactions occur" (grade 10); and to "[recognize] that all organisms have chromosomes made of DNA and that DNA determines traits" (grade 9). While true, these statements are so general that they provide no meaningful content or direction as to what students should know or be able to do.

One bright spot is physiology, which is reasonably well covered and includes several clear and rigorous standards. For instance, in tenth grade, students are asked to "[explain] the functions of organs of major systems (i.e., respiratory, digestive, circulatory, reproductive, nervous, musculoskeletal, and excretory)." Unfortunately, the incongruous presence of this specific section amid all the vagueness looks more like a freak accident than a glimpse of substance.

To its (limited) credit, Alaska does not split hairs about evolution, at least in principle. In the introductory material, the standards say that a student who meets the "concepts of life" standard should "develop an understanding of how science explains changes in life forms over time, including genetics, heredity, the process of natural selection, and biological evolution," among other things.

Sadly, that admirably straightforward requirement fizzles quickly with the absence of follow-through. Without specific content to support it, the statement of purpose loses force.

Given Alaska's mountainous errors and sweeping generalities, the state can earn no more than a one out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

While the Alaska standards are generally clearly written and easy to follow, the lack of specificity makes them virtually useless. Nothing short of scrapping this document and starting from scratch (or borrowing the recipe of one of the nation's "A" states) could result in a useful basis for curriculum writing, test preparation, and textbook writing.

Worse, on the rare occasions where the Alaska standards do strive for specifics, they often—dismayingly often—miss the mark.

Consider the eighth-grade section on chemistry, which asks students to demonstrate "an understanding of the interactions between matter and energy and the effects of these interactions on systems by exploring changes of state with increase or decrease of particle speed associated with heat transfer" and by "exploring through a variety of models (e.g., gumdrops and toothpicks) how atoms may bond together into well defined molecules or bond together in large arrays."

Exactly how does one demonstrate by exploring? What does it mean to explore? Go into the lab and watch ice cubes melt or water boil? How can these activities be connected to the speed of particles? (More likely the writers meant molecules, an unfortunate use of the wrong terminology.) From the standards, at least, it's impossible to say.

This overabundance of buzzwords (like "demonstrate" and "explore") further clouds the state's already-murky science material. As such, Alaska's score for clarity and specificity is a troubling one out of three. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Arizona

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	3/7	4/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**2.8**
Scientific Inquiry & Methodology	5
Physical Science	4
Physics	0
Chemistry	0
Earth & Space Science	5
Life Science	3
Clarity & Specificity	**1.0**

Average numerical evaluations

Document(s) Reviewed[1]

- *Arizona Science Standards, Articulated by Grade Level*. March 2005. Accessed from: http://www.azed.gov/standards-practices/science-standard/

[1] Fordham's 2005 evaluation also reviewed Arizona's 2005 content-standards document. Since 2005, we have updated and improved the evaluation criteria used to judge the standards. (See Appendix A for a complete explanation of criteria used in this review.) Through this new lens, Arizona's science grade dropped from a B to a D. The complete 2005 review can be found here: http://www.edexcellence.net/publications-issues/publications/sosscience05.html.

Overview

Arizona's science standards are generally weak on content and are plagued by disorganization and a frustrating lack of cohesion. These weaknesses undermine the ability of the material to serve as the foundation for a comprehensive K-12 science curriculum.

Organization of the Standards

Arizona's K-8 science standards are divided first into six strands: inquiry process; history and nature of science; science in personal and social perspectives; life science; physical science; and earth and space science. Each strand is then divided into a series of "concepts," and finally, grade-specific standards are provided.

The high school standards are presented similarly, except that only one set of standards is presented for all grades, 9-12. High school physics, chemistry, and biology are not covered as separate subjects.

Content and Rigor

While it is not always treated with adequate depth or rigor, much of the essential K-8 content students should learn is covered by the Arizona standards. Unfortunately, coverage of critical high school science material is spotty and unsystematic. In fact, the standards at this level read more like a general outline—or perhaps a set of scrambled chapter titles from a textbook—than a comprehensive set of standards.

Scientific Inquiry and Methodology

Arizona's standards addressing scientific inquiry and methodology are reasonably strong. Both process and history of science receive explicit mention. Attempts to set evolutionary theory into a category separate from and inferior to other scientific theories are anticipated and successfully negated by asking students to consider "how scientists continue to investigate and critically analyze aspects of [all scientific] theories" (grades 9-12).

Unfortunately, there are drawbacks, too. A few of the examples of historical figures who "have made important contributions to scientific innovations" seem relatively trivial, as if favoring inclusiveness over universal significance. Take the following examples: Sally Ride (grade 1); Daniel Hale Williams, Charles Drew, and Elizabeth Blackwell (grade 2); Percy Lavon Julian (grade 5); and Walter and Luis Alvarez (grade 7). In addition, Arizona places far too much emphasis on inquiry, history and nature of science, and science in personal and social perspectives.

Physical Science/High School Physics/High School Chemistry

The physical science standards for Kindergarten through eighth grade have occasional flashes of competence, though never brilliance. The coverage of dynamics, for example, is very good.

Unfortunately, there are also many shortcomings. The "concepts" under which the standards are grouped are often poorly conceived. For example, one is called "energy and magnetism." Why would these two subjects be conjoined when work belongs with energy and electricity with magnetism?

Making matters worse, the standards grouped beneath each concept often defy explanation. For instance, a Kindergarten standard that asks students to "investigate how applied forces (push and pull) can make things move" is oddly grouped under "energy and magnetism" rather than under "motion and forces."

Adding to these organizational problems, the content of the standards is problematic. For instance, while students are introduced to forces and motion in Kindergarten, they must wait until fifth grade to finally discern the connection between the two concepts, and it isn't until eighth grade that they make a full-fledged, if likely only partially quantitative, study of Newton's laws.

Furthermore, the earliest mention of energy in the physical sciences is in sixth grade, where four standards address electrical generation, energy storage, methods of transforming energy, convection, conduction, and radiation. Up to that point, however, there has not been (and never is) a definition of energy or a discussion of the relation between work and energy, of kinetic and potential energy, or of anything other than the practical applications just noted. The only follow-up, in eighth grade, asks students to "investigate how the transfer of energy can affect the physical and chemical properties of matter." A tall order, indeed.

The chemistry standards for Kindergarten through eighth grade are equally problematic. For starters, chemistry content is again mostly relegated to fifth and eighth grades. There is woefully little background chemistry material for Kindergarten through fourth grade, and nothing in sixth and seventh grades. Indeed, the "chemical reactions" concept, which embraces all of chemistry, appears only at the high school level.

The high school standards covering both chemistry and physics are also distressingly inadequate. All of high school chemistry is covered in eleven vague sentences. And, while the standards do include a glossary that defines essential scientific terms, equilibrium—a fundamental concept of chemical reactions—is missing. In short, the content needed to inform traditional high school chemistry and physics courses is largely absent from the Arizona standards.

Earth and Space Science

The Arizona standards document addresses (or at least skims over) a great deal of earth and space content. Laudably, the concept of gas is introduced with care in second grade, both in general and in the context of the states of water. The treatment of basic astronomy is solid in fifth and seventh grades. Astronomy, however, is mostly limited to the solar system until high school. The discussion of rocks and fossils in third grade is strong, and some mention of earth structure and plate tectonics appears in seventh grade. By fleshing out the individual standards with more specific content and detail, Arizona's earth and space science standards could be excellent.

Life Science

What material is presented in Arizona's life science standards is clear and progresses adequately through the grades. Unfortunately, there are holes in the content, leaving Arizona teachers with a weak skeleton upon which to build a rigorous life science curriculum. In areas important to grasping modern biology, for example, the standards are skimpy, particularly prior to high school. For example, there is only one unit on the topic of heredity in eighth grade, which gives no indication of how the principles are to be taught:

> **Explain the basic principles of heredity using the human examples of:**
>
> - **eye color**
> - **widow's peak**
> - **blood type. (grade 8)**

This sparseness of content extends to high school, where molecular biology and genetics get little attention. Similarly, in the high school unit on evolution, there are bullet points that include most important key words, but little development of any of the concepts.

There are a few exceptions to the rule: Ecosystems are well covered from Kindergarten through eighth grade, and the early coverage of physiology is quite robust. Beginning in second grade, we have such examples:

> **Describe the basic functions of the following systems:**
>
> - **digestive – breakdown and absorption of food, disposal of waste**
> - **respiratory – exchange of oxygen and carbon dioxide**
> - **circulatory – transportation of nutrients and oxygen. (grade 2)**

One may wonder whether the typical second grader can manage material of this sophistication, but a strong teacher could properly pitch the essential information at the appropriate level of rigor. But there is no coverage of physiology at all at the high school level, which is disappointing, given this solid introduction in the early grades.

While the Arizona standards occasionally cover key scientific topics with the appropriate level of depth and rigor, their drawbacks are significant, and the amount of content missing—particularly at the high school level—leaves the Grand Canyon State with an average score of three out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Arizona standards suffer from two significant drawbacks. First, they frequently lack the specificity needed to drive rigorous curriculum development and instruction. Consider, for example, the following earth and space science standard:

> **Analyze the evidence that lithospheric plate movements occur. (grade 7)**

In this case, there are many lines of evidence. Which should the students analyze—and what should that analysis consist of?

Similarly, this life science standard describes all of biochemistry in fewer than twenty words:

> **Describe the role of organic and inorganic chemicals (e.g., carbohydrates, proteins, lipids, nucleic acids, water, ATP) important to living things. (grades 9-12)**

Sadly, these are not isolated cases.

Second, the organization and presentation of the document is a mess. With a few exceptions, notably the "diversity, adaptation, and behavior" concept, the standards consist of little more than broad lists of topics without proper sequencing or development.

Taken together, these drawbacks leave Arizona with an average score of one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Arkansas

GRADE	SCORES		TOTAL SCORE
B	Content and Rigor	5/7	7/10
	Clarity and Specificity	2/3	

REPORT CARD

Content & Rigor	**5.2**
Scientific Inquiry & Methodology	2
Physical Science	5
Physics	7
Chemistry	7
Earth & Space Science	3
Life Science	7
Clarity & Specificity	**2.0**

Average numerical evaluations

Overview

Arkansas presents a well-organized and generally sound set of science standards, with thorough and excellent treatment of most—though not all—disciplines. Curricula that are well aligned to this document ought to be solidly grounded and, provided they are staffed by scientifically competent teachers, classrooms of the Natural State could do a fine job of science education.

Organization of the Standards

Arkansas's K-8 standards are divided into four strands: nature of science, life science, physical science, and earth and space systems. Each strand is sub-divided into two or three "standards," covering broad notions such as "characteristics and processes of science" and "living systems: characteristics, structure, and function." The standards are further divided into subheadings, and finally into grade-level expectations.

At the high school level, the standards are presented similarly except that course-specific expectations, rather than grade-level expectations, are presented for anatomy and physiology, biology, chemistry, environmental science, physical science, and physics.

Content and Rigor

The Arkansas standards do many things well. For nearly every discipline (earth and space science and physical science excepted), they cover all of our critical points of content with sufficient rigor and at the appropriate grade level. The examples are explicit and generally spot-on, and concepts develop over advancing grade spans—both of which make it easy to trace the accumulating knowledge that students will obtain as they progress through the school system.

Scientific Inquiry and Methodology

The scientific inquiry and methodology standards, presented within the "nature of science" strand, are the worst of the bunch. Here, students are asked to "demonstrate and apply knowledge of the characteristics and processes of science using appropriate safety procedures, equipment, and technology." Unfortunately, the skills that they are to acquire in achieving this goal are aphoristic and hopelessly vague. For example,

Document(s) Reviewed

- *Arkansas K-8 Science Curriculum Framework*. Revised 2005. Accessed from: http://arkansased.org/educators/pdf/science_k-8_011006.pdf
- *Arkansas High School Science Curriculum Frameworks*. Revised 2005. Accessed from: http://arkansased.org/educators/curriculum/frameworks.html#science

students in fifth grade are asked to "summarize the characteristics of science." One hopes their instructors have a clear idea of what these "characteristics" are, because the standards give no indication.

Similarly content-free standards can be found throughout. Fourth graders are asked to "evaluate the quality and feasibility of an idea or project," with no hint as to how they might make such an evaluation. Fifth graders are expected to "make accurate observations," but it is only in sixth grade that they are expected to verify the accuracy of their observations. One must wonder how they knew in the previous grade that they were meeting their goals of accuracy. At the high school level, students "research historical and current events" in the content areas. But the standards give no indication of what events students are meant to investigate, or even to what end students should be doing such research.

Physical Science

The Arkansas physical science standards are generally strong, and most of the basic concepts are introduced at the proper grade level. Beginning in second grade, students make measurements in SI (standard *Système International d'Unités*, or International System of Units) with the range of measurements expanding systematically grade by grade. Force and motion are introduced in second grade. Force and direction, as well as force and mass, are introduced in fourth grade. Eighth graders receive a solid treatment of waves.

Arkansas's presentation of physical science is well constructed. Covered in the chemical section are kinetic theory, latent heats, the triple point, and Boyle's and Charles's laws (though not the ideal gas law). Kinematics and dynamics are developed systematically, using equations as necessary. Conservation of momentum is covered, and energy is addressed even more completely. As in the lower grades, the high school treatment of waves, including both sound and light, is clear.

The standards include an unusually complete discussion of some basic concepts of organic chemistry, including carbon-carbon bonds, allotropes, structural formulas, and types of compounds with biological functions.

High School Physics

The treatment of high school physics is excellent. The document perhaps goes overboard in expressing ideas in mathematical form; it would be better to have more explanatory text, as equations by themselves tend to be narrow in scope. But the physics standards cover pretty much what one would encounter in a college-level non-calculus physics course. Indeed, the physics standards read almost like an abridged textbook. The sequence is traditional and thorough: one-dimensional kinematics; one-dimensional dynamics; vector analysis; two-dimensional mechanics (including parabolic trajectories and motion under a central force); Newton's law of gravitation; work; the work-energy theorem; impulse and momentum; and collisions. Following this come equally thorough and correct treatments of fluid dynamics and thermodynamics, the latter including a proper, if brief, handling of Newton's second law and a discussion of heat engines. Simple harmonic motion is covered, followed by geometric optics; curiously, wave optics and waves in general are mentioned only in passing. Treated briefly but carefully are electrostatics and electromagnetism, with explicit mention of Faraday's law. Quantum phenomena are covered briefly as well.

High School Chemistry

The Arkansas chemistry standards are particularly strong; all of our content criteria—and much more—are thoroughly covered by the Arkansas standards. A number of topics are especially comprehensive. These include chemical bonding, stoichiometry, and organic chemistry. The treatment of gases is also extensive and doesn't shy away from calculations. It includes: relating kinetic theory to molecular motion, elastic collisions, temperature, and pressure; calculations of the effects of pressure, temperature, and volume on the number of moles of gas particles in chemical reactions; calculations with all the gas laws again connecting p, V, T, and moles of a gas (the names and formulas were given for the following laws: Avogadro's, Boyle's, Charles's, combined, Dalton's, Graham's, Gay-Lussac's, and the ideal gas law); and calculations of mass and gaseous volume relationships, based on the stoichiometry of balanced chemical equations.

Further adding to the high school chemistry material, Arkansas provides a five-page glossary of generally well-written terms. The definition for "base," for example, gave: "A substance which produces hydroxide ions in water solution ([A]rrhenius); a proton acceptor (Brønsted); an electron pair donor (Lewis)."

These glossary definitions further exemplify the depth and attention to detail found in the Natural State's chemistry standards. Whereas most states barely ask students to know that bases provide hydroxide ions in water (and don't give credit to Arrhenius), Arkansas students are required to know these more advanced concepts. The 2005 chemistry revision committee should be congratulated for producing such a comprehensive document.

Earth and Space Science

The K-8 earth and space science standards cover a good deal of content. Unfortunately, though the standards have adequate breadth, they often lack depth. For example, in third grade, students are asked to:

> **Describe the layers of Earth:**
>
> - **crust**
> - **mantle**
> - **inner core**
> - **outer core (grade 3)**

Unfortunately, this standard leaves far too much interpretation to the teacher or curriculum developer. Worse, the standard repeats, hardly changed, in sixth grade. This makes it unclear when and how the thickness of the crust and the relative average density of continental versus ocean crust, brittleness, and so forth are supposed to be taught. Unfortunately, the other standards are similarly vague.

The Arkansas standards do not include earth and space science standards in high school, although the environmental science document contains a rather brief section titled "physical dynamics." This section has only nineteen entries, many of which are quite broad. For example, students are asked to:

> **Describe the structure, origin, and evolution of the Earth's components:**
>
> - **atmosphere**
> - **biosphere**
> - **hydrosphere**
> - **lithosphere (high school environmental science)**

This, like the other eighteen standards, fails to delineate what, specifically, students need to know or be able to do, leaving the high school earth and space content rather sparse.

Life Science

The life science standards are well organized. Concepts are developed carefully through the grade levels and there is good balance among subjects.

Evolution is treated unflinchingly, which is a great step forward for Arkansas. While the concept of evolution is not explicitly presented as the central organizing principle of biology, the coverage begins with a study of fossils in fifth grade and receives appropriately progressive treatment from then on.

High school biology is also excellent. For example, students are asked to "analyze the meiotic maintenance of a constant chromosome number from one generation to the next." The standards for biochemistry, cell biology, and genetics are all impressive for their depth and rigor.

In addition, students are required to spend time on dissections. The standards mention several times, for example, that there will be a dissection of a poultry egg (presumably a chick embryo) in seventh grade. While this is a tricky dissection, the very idea of even *looking* at a chick embryo in seventh grade is a great one.

That said, there are occasionally some curious expectations. For instance, the standards require fifth graders to dissect both eyes and lungs—messy tissues that make this exercise impractical at this level.

Overall, the strengths of the Arkansas standards far outweigh the weaknesses and earn the Natural State a solid average score of five out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Arkansas standards are generally systematic and clearly presented. But there are notable lapses. As noted above, the inquiry and methodology guidelines are hopelessly vague. And too many standards fail to specify what, precisely, students should know and be able to do. For example, a fourth-grade physical science standard asks students to "investigate the relationship between force and direction." It's unclear how a nine- or ten-year-old would go about investigating such a relationship, nor what relationship he or she is expected to discover.

Similarly, in third grade, students are asked to "differentiate between magnets and non-magnets." Beyond saying "this is a magnet and this isn't," it's unclear what Arkansas is asking of its students.

Finally, a seventh-grade standard asks students to "compare and contrast Newton's three laws of motion," but it's not entirely clear why this is a useful exercise. Many other verbs would have made more sense; such as "describe," "explain," or even "use" (although this last is likely premature in seventh grade).

At least this silliness receives redemption in what immediately follows, when students are asked to:

> **Conduct investigations demonstrating Newton's first law of motion**
>
> **Demonstrate Newton's second law of motion**
>
> **Conduct investigations of Newton's third law of motion. (grade 7)**

These standards are clear and specific and their ordering is especially laudable, considering how many states compress all three of Newton's laws into a single sentence.

Finally, Arkansas would have done well to jettison—or at least overhaul—the glossary appended to the K-8 document. As it stands, it is risible. Here are some examples:

> **Absorption: When white light wave passes through a substance the energy of certain colors may be taken in by the substance and converted to a different form of energy.**

This is a mélange of fifth-grade syntax with eighth-grade understanding.

> **Chemical change: Any change where one or more of the original materials changes into other materials.**

These "other materials," we suppose, being chemically different from the original ones?

> **Transparent: The ability of light to pass through without refraction.**

Except, of course, for the 100 percent of transparent materials at whose surfaces light beams refract. (Course-specific glossaries in high school, however, fared better.)

Taken together, these strengths and weaknesses earn the Natural State an average score of two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

California

GRADE	SCORES		TOTAL SCORE
A	Content and Rigor	7/7	10/10
	Clarity and Specificity	3/3	

REPORT CARD

Content & Rigor	**6.7**
Scientific Inquiry & Methodology	5
Physical Science	7
Physics	7
Chemistry	7
Earth & Space Science	7
Life Science	7
Clarity & Specificity	**3.0**

Average numerical evaluations

Document(s) Reviewed[1]

- *Science Content Standards for California Public Schools*. 1998. Accessed from: http://www.cde.ca.gov/be/st/ss/documents/sciencestnd.pdf
- *Science Framework for California Public Schools*. 2005. Accessed from: http://www.cde.ca.gov/ci/cr/cf/documents/scienceframework.pdf

[1] California's academic content standards have not changed since Fordham's 2005 evaluation. However, the evaluation criteria used here have been updated and improved since 2005. (See Appendix A for a complete explanation of criteria used in this review.) Even through this new lens, California's science grade remained an impressive A. The complete 2005 review can be found here: http://www.edexcellence.net/publicationsissues/publications/sosscience05.html.

Overview

The California science standards are truly excellent. The standards themselves are reasonably succinct yet quite comprehensive. This is especially true in high school chemistry, where topics are covered that are rarely seen in other K-12 standards documents. The continuity from grade to grade is superb, thanks in part to the introductory commentary and context that the state provides, which relate grade-specific learning to standards that have been covered in earlier grades, and those that will be covered later.

Organization of the Standards

The *Science Content Standards for California Public Schools* include grade-specific content for grades K-8. Grades K-5 cover earth and space sciences, life sciences, and physical sciences, all to varying degrees. Earth and space sciences are then focused on in sixth grade, life sciences in seventh grade, and physical sciences in eighth.

At the high school level, standards are presented by content area (rather than by grade) for physics, chemistry, biology/life sciences, and earth sciences.

Along with the content-specific standards, each grade level or high school content area includes a strand titled "investigation and experimentation," which acquaints students with the scientific method.

Building off the *Science Content Standards* is the *Science Framework for California Public Schools*. This document offers more background and explanation than the standards—including outlines for assessments, for professional development, and for special-education instruction. Specifically relevant to this review, chapters three through five of the *Framework* present detailed explanations of each of the standards, including clarifying examples.

These expansions are well done—almost like an abridged textbook. They are clear, systematic, and free of any really serious errors (though some small mistakes creep in).

Content and 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.

Scientific Inquiry and Methodology

In our last review, published in 2005, we noted:

> **On science processes, and on history and philosophy of science, California's standards vary delightfully from the norm: They are *brief*, there is no bombast, and they are realistic about the capacities of children for making sense of abstract ideas. Process is stressed where it should be, and in plain and appropriate language. For example: Grade 3: "Repeat observations to improve accuracy, and know that the results of similar scientific observations seldom turn out exactly the same. ...Differentiate evidence from opinion and know that scientists do not rely on conclusions unless they are backed by observations that can be confirmed."[2]**

This still holds. However, these otherwise exemplary standards make no mention of the historical and social aspects of the scientific endeavor from Kindergarten through eighth grade and do so only briefly in high school. There we read, for example, "Investigate a science-based societal issue by researching the literature, analyzing data, and communicating the findings" and "Know that when an observation does not agree with an accepted scientific theory, the observation is sometimes mistaken or fraudulent...and that the theory is sometimes wrong." While there is nothing wrong with this statement, it adds no particular value.

Physical Science

The coverage in physics, chemistry, and astronomy is thorough and logical, particularly in the primary-grade standards. The supporting material generally adds significant value across all grades. For instance, in physics (and to some extent in chemistry) the inclusion of mathematical statements is extensive, beginning in eighth grade.

While the standards are generally error-free and comprehensive, some gaffes occasionally appear in the frameworks. Take, for example, the following statement from the sixth-grade standards:

> **Energy can also be transferred by the movement of matter. For example, the energy supplied by the pitcher's arm transports a pitched baseball to the catcher's mitt. (grade 6)**

This explanation is somewhat garbled. What is important here is the energy transported from the pitcher's arm to the catcher's mitt (the catcher feels it in the impact), not the baseball itself.

Likewise, in eighth grade, students are told that "an experiment by Galileo resulted in the discovery of friction." Galileo discovered many important things, but friction wasn't one of them.

High School Physics

The high school physics standards can easily provide the foundation for an excellent course. Subjects are treated in logical order, with mathematical expressions used as necessary. Particularly remarkable (and, unfortunately, unusual in state science standards) is the excellent treatment of heat and thermodynamics. The treatment of the laws of thermodynamics (especially the first law) and of heat engines are far superior to any we have seen in other state science standards.

Curiously, though, some physics content is presented in the chemistry section, including radioactivity, fundamental particles (quarks, etc.), kinetic theory, and the gas laws.

Ampère's and Faraday's laws are not discussed explicitly, but there is some discussion of electromagnetic induction (changing magnetic fields produce electric fields) and its complement (changing electric fields produce magnetic fields).

A slip that is particularly curious in a California publication is this statement from the *Framework*:

> **The first accelerator was developed in the 1950s in Berkeley, California. (grades 9-12)**

Ernest O. Lawrence and his colleagues achieved fame at Berkeley in the 1930s for the development of the cyclotron, one of the earliest types of particle accelerators. But this statement seems to be the result of conflation of particle accelerators in general and the Bevatron, the first one to achieve energies sufficient to produce antiprotons.

The naming of the electron is attributed, incorrectly, to J. J. Thomson. The electron was actually named in 1891 by the Irish physicist G. Johnstone Stoney on theoretical grounds before it was actually observed.

[2] Paul R. Gross, *The State of State Science Standards 2005* (Washington, D.C.: Thomas B. Fordham Institute, 2005), http://www.edexcellence.net/publications-issues/publications/sosscience05.html.

High School Chemistry*

Chemical bonds are treated extensively and completely in high school, building upon the groundwork laid earlier. As noted above, kinetic theory and the gas laws are covered within the chemistry standards, but are well treated there. In particular, there is an explicit discussion of Boyle's and Charles's laws as special cases of the ideal gas law, with a table to show the conditions under which each is valid. Acid-base chemistry, solutions, and chemical equilibria are among the topics covered with elegance and clarity. For example:

> **Students should be able to compare the three descriptions of acids and bases—the Arrhenius, Brønsted-Lowry, and Lewis acid-base definitions—and recognize electron lone pairs on Lewis dot structures of molecules (see Standard Set 2, "Chemical Bonds," in this section). To calculate pH, students should understand and be able to use base-10 logarithms and antilogarithms and know how to obtain logarithms by using a calculator. Students should become proficient at converting between pH, pOH, [H] and [OH-]. (grades 9-12)**

Earth and Space Science*

Like so many of the California standards, the earth and space science standards are thorough and appropriately rigorous. They're not perfect, however.

One may legitimately carp, for example, at the "explanation" of the Coriolis force. The writers would do better to avoid explanation of complicated topics like this than to give incorrect ones.

The discussion of gravitation in the solar system in fifth grade has some confusing and incorrect statements. We read, "[The Sun's] mass can be calculated from the shapes of the planetary orbits ..." Not true. "Asteroids and comets are small bodies, most of which are in irregular orbits about the Sun." Not unless an eccentric ellipse counts as "irregular."

But these rare confusions are more than balanced by admirable statements, such as this one in sixth grade: "Students know how to determine the epicenter of an earthquake and know that the effects of an earthquake on any region vary, depending on the size of the earthquake, the distance of the region from the epicenter, the local geology, and the type of construction in the region." This example is semi-quantitative, involves practical knowledge, and deals with earthquakes as phenomenon.

Life Science

The life sciences are equally strong. Evolution is well presented as the central organizing principle of the life sciences, with good cross-references to geology, paleontology, and cosmology. Treatment of genetics and population genetics, and the development of contemporary evolutionary biology in the context of the latter, are sound, timely, and clearly written. Fossils and the fossil record are introduced thoughtfully in second, third, and sixth grades. But given the otherwise careful selection of important implications of the main science themes—including the key themes of biology—it is perplexing that human evolution is never explicitly mentioned, though it is clearly implied in the broad sweep of life science content covered.

As one can see from the examples cited above, the California standards are not completely free from error. But these are such minor errors with so little impact on the whole, that we do not hesitate in assigning a perfect score—seven out of seven—to the whole for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and 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. The California science standards easily earn a perfect score of three out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

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* Two of our reviewers, Martha Schwartz and Rick Schwartz, contributed to the writing of the California science standards. Therefore, these reviewers abstained from commenting on the documents. Lead reviewer Lawrence Lerner, along with the others on the team, reviewed the chemistry and earth and space science sections in their stead.

SCIENCE

Colorado

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	2/7	3/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**2.3**
Scientific Inquiry & Methodology	7
Physical Science	3
Physics	0
Chemistry	0
Earth & Space Science	1
Life Science	3
Clarity & Specificity	**0.8**

Average numerical evaluations

Overview

The Colorado standards begin with a mistranslation of renowned French mathematician Henri Poincaré's famous aphorism: "On fait la science avec des faits, comme une maison avec des pierres, mais une accumulation de faits n'est pas plus une science qu'un tas de pierres n'est une maison." A reasonable translation reads like this: "Science is made of facts, [just] as a house is made with stones, but an accumulation of facts is no more a science than a pile of stones is a house." The standards writers, however, came up with this:

> **Science is facts; just as houses are made of stone, so is science made of facts; but a pile of stones is not a house, and a collection of facts is not necessarily science.**

Alas, the muddled translation portends a confused and misguided presentation of content that at times "is not necessarily science" at all.

Organization of the Standards

Colorado's *Academic Standards* document first divides the standards into three strands: life science, physical science, and earth and space science. For each strand, the state provides a set of three or four "prepared graduation competencies," which explain broadly what students must know and be able to do upon graduation. Finally, grade-level expectations are presented from pre-Kindergarten through eighth grade. Only one set of standards is provided for high school.

Each of the grade-level expectations is coupled with a corresponding set of "evidence outcomes" as well as "21st century skills and readiness competencies," defined by inquiry questions, relevance and application, and nature of science.

The organization of Colorado's science standards is confusing in its hierarchy. The document *begins* by presenting the high school expectations, regressing back, grade by grade, to those of pre-Kindergarten. The tight, systemic structure of science is instantly compromised by this choice, as more complex concepts are unable to build upon earlier and more basic concepts in the standards.

Document(s) Reviewed

- *Colorado Academic Standards: Science*. Adopted December 10, 2009. Accessed from: http://www.cde.state.co.us/cdeassess/UAS/AdoptedAcademicStandards/Science_Standards_Adopted_12.10.09.pdf
- *Colorado Science Standards and Expanded Benchmarks*. 2005. Accessed from: http://www.cde.state.co.us/cdesped/download/pdf/Expanded_Benchmarks_Science.pdf

Content and Rigor

The material presented suffers from a serious lack of clarity, depth, and sufficient content. The standards have a frustrating tendency to string together numerous properties without explanation.

The grade-level expectations from pre-Kindergarten through seventh grade are quite low, lacking sufficient rigor throughout. In these grades, students are exposed to only one narrow subject each year, making any judgment of progress through grade levels impossible. Then, in eighth grade, exactly when students should be *specializing* in one of the sciences each year, the scope of the standards becomes much broader. It's hard to imagine how Colorado students will ever study essential scientific content at the appropriate level of depth and rigor with this confused and illogical presentation.

Scientific Inquiry and Methodology

This area stands out as the only one that is well covered. In the "Overview of Changes," the writers note that "the largest change to the science standards is acknowledging that scientific inquiry, science process skills, and content cannot be taught separately." Consistent with this statement, these standards focus solely on three disciplinary strands (life, physical, and earth sciences). "Scientific investigations" and "nature of science," both strands found in the previous iteration of Colorado's standards, have been subsumed into these three disciplinary strands.

Inquiry and process-skills material is now interwoven with disciplinary content, so that each conceptual expectation has associated nature-of-science competencies. For example, the eighth-grade physical science standard that asks students to "distinguish between physical and chemical changes, noting that mass is conserved during any change" is linked with the twenty-first-century (inquiry) skill "share experimental data, and respectfully discuss conflicting results emulating the practice of scientists." Overall, the inquiry material is clearly integrated with the conceptual, and historical/ethical matters receive some coverage.

Physical Science/High School Physics/ High School Chemistry

The physical science standards are generally weak, with a few bright spots appearing in the early grades. For starters, in first grade, students are asked: "What do all liquids have in common? What are some differences they can have and still be considered liquids? What do all solids have in common? What are some differences they can have and still be considered solids?" These inquiry questions provide a clear and grade-appropriate introduction to solids and liquids.

But such standards are the exception. More typically, we have such bewilderments as this, in eighth grade: "Identify and calculate the direction and magnitude of forces that act on an object, and explain the results in the object's change of motion." The implication here is that the eighth grader has completed studies of kinematics and dynamics, so that he or she can calculate the effects of force on the motion of an object. Of course the standards have not provided this critical prerequisite content, so the exercise is pointless.

Sixth graders are instructed to "develop an evidence-based scientific explanation of the atomic model as the foundation for all chemistry." Go to it, kids!

Chemistry is presented unsystematically and confusingly throughout the grades. In high school, for example, students are required to "predict and calculate the amount of products produced in a chemical reaction based on the amount of reactants," but the mole concept, essential to this exercise, has never been introduced. And there seems to be no material for high school physics.

Finally, too many standards are plagued by infelicities and plain errors. Some of the worst include: "Classify objects based on chemical properties (the ability of something to react) (e.g., ...vinegar's ability to react with vinegar)." Or this: "Describe transformation of forms of energy in terms of motion (e.g., fast, slow)," which means nothing at all. Or perhaps most distressingly, "Understand that a change in force will cause a change in speed an[d]/or direction of the object." This is the classical error of Aristotle—velocity is proportional to force—that Galileo went to so much trouble to demonstrate and supersede!

Earth and Space Science

A student who wants to learn about the structure of Earth will get little help here. The term "crust" appears exactly once, in sixth grade: "Use a computer simulation for Earth's changing crust." And there is nary a mention of either the mantle or the core.

The rock cycle appears once, in third grade, in the garbled phrase, "Earth's materials can be broken down and/or combined into different materials such as rocks, minerals, rock cycle, formation of soil, and sand—some of which are usable resources for human activity."

Sadly, these examples are the rule, rather than the exception, making the standards for earth and space science woefully inadequate.

Life Science

What aspects of life science will be covered in Colorado classrooms is a mystery. One searches the document in vain for any mention of the following basic terms: Mendel, mitosis, meiosis, mitochondrion, nucleus, prokaryote/eukaryote, and gamete.

The level of difficulty of the material presented varies wildly. At one extreme, students in high school are expected to study the energy involved in cell-membrane transport; the relevant data are, in fact, highly sophisticated, but there is not a hint as to how students would come to understand these data sufficiently to offer such interpretations. Kindergartners are supposed to compare and contrast data and question their peers about the evidence used in developing their ideas. Even preschoolers are supposed to predict, explain, and infer patterns based on observations.

At the other extreme, we have such trivialities as these: "Agriculture is of great importance to humans. For example, most food comes from agriculture" (grades 9-12). The creationist ploy of inviting students to study "strengths and weaknesses" of well-established biological knowledge seems to have sneaked into the Colorado standards through the back door. Students must "critically evaluate models used to represent deoxyribonucleic acid (DNA) and genes; identify strengths and weaknesses of these models for representing complex natural phenomena" (grade 8).

But as all practicing biologists know, there are no weaknesses in DNA models to discuss. Another example: "Critically evaluate models for photosynthesis and cellular respiration, and identify their strengths and weaknesses" (grades 9-12). Here again, the weaknesses are a figment of an untrained imagination.

Despite Poincaré's warning, the Colorado standards writers have passed off a pile of stones as a house. If not for the inquiry standards, the house would surely collapse. With them, the Centennial State earns a meager average score of two out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Colorado standards are as confusing as they are devoid of critical content. For starters, the backward organization of the standards makes it very hard to follow the development of a scientific idea as the student learns the simplest aspects as a child and progresses in sophistication as he moves on toward adulthood.

The writing is also repetitious and awkward—and at times ungrammatical. Some of the material is simply baffling. Stellar evolution is touched on in eighth grade in a garble: "How is the life cycle of a star such as the Sun similar to the cycle of life on Earth?" How, indeed! Absent any specific information about what, precisely, the state expects students to know and be able to do here, this standard is virtually meaningless.

And here's a honey of a quotation: "Analyze and interpret data on homeostatic mechanisms using direct and indirect evidence to develop and support claims about the effectiveness of feedback loops to maintain homeostasis" (grades 9-12). What that means, who really can say?

If these blunders were merely sour notes in an otherwise harmonious performance, it might be possible to overlook them. But they are set against a totality of information that suffers from a serious lack of clarity, depth, and sufficient content, and the standards therefore earn a one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Connecticut

GRADE: **C**

SCORES:
Content and Rigor **4/7**
Clarity and Specificity **2/3**

TOTAL SCORE: 6/10

REPORT CARD

Content & Rigor	**4.0**
Scientific Inquiry & Methodology	2
Physical Science	5
Physics	4
Chemistry	4
Earth & Space Science	5
Life Science	4
Clarity & Specificity	**1.8**

Average numerical evaluations

Document(s) Reviewed[1]

- *Connecticut Core Science Curriculum Framework*. 2005. Accessed from: http://www.sde.ct.gov/sde/lib/sde/word_docs/curriculum/science/framework/sciencecoreframework2005v2.doc
- *Connecticut PreK-8 Science Curriculum Standards Including Grade-Level Expectations*. 2009. Accessed from: http://www.groton.k12.ct.us/cms/lib2/CT01001200/Centricity/Domain/47/PK8_sciencecurriculumstandards2009.pdf
- *Connecticut Core Science Curriculum Framework: Matrix of K-10 Concept Development*. 2005. Accessed from: http://www.sde.ct.gov/sde/lib/sde/word_docs/curriculum/science/framework/matrix2005.doc

[1] In 2011, Connecticut released an updated version of its preK-8 grade-level expectations (dated 2010). Following this review of the 2009 document, we present a brief comparison review of the 2010 version.

Overview

The Connecticut science standards are generally well written, with but a few scientific errors or badly phrased statements. Unfortunately, a significant amount of important material is missing, preventing the Constitution State from earning top marks across the board.

Organization of the Standards

The Connecticut science standards include three documents: the main *Curriculum Framework* document, a *Grade-Level Expectations* document, and a *Matrix of K-10 Content Development*. Within the *Framework*, Connecticut's science standards are organized around eleven conceptual themes, such as inquiry, forces and motion, the changing Earth, and science and technology in society. For each theme, the state provides several grade-specific content standards and "expected performances" that illustrate what will be assessed on the state tests.

The high school standards are organized similarly, with two exceptions. First, the conceptual themes for ninth and tenth grades are further subdivided into five strands. Strands I, II, and III speak to the physical sciences, and strands IV and V to the life sciences. Second, the content standards for eleventh and twelfth grades—as well as those for the high school physics, chemistry, earth science, and biology courses—are articulated through the state's "enrichment curriculum" at the end of the document.

In addition, the state offers a grade-level expectations document for grades preK-8 to support the *Framework*. This document repeats all the material that is in the curriculum framework, and adds grade-level expectations that further clarify each content standard.

Finally, the state provides the *Matrix of K-12 Content Development*, which briefly (in six pages) describes the "progressive development of conceptual themes" in scientific inquiry, earth science, life science, and physical science for each grade, preK-8, and then for high school.

All of the science standards documents say much the same thing, although in quite different ways—increasing the risk that the material will confuse readers.

Content and Rigor

The Connecticut standards are generally strong and cover most of the important topics in science with adequate depth and rigor. The one notable exception is the scientific inquiry and methodology standards, which are overly brief and provide little guidance about what knowledge and skills students should learn.

Scientific Inquiry and Methodology

As mentioned above, the scientific inquiry and methodology standards are the weakest of the Connecticut standards. The expectations emphasize acquisition of three (cognitive) skills—scientific inquiry, scientific literacy, and scientific numeracy—but the associated standards comprise a mere four pages. So, for example, students are expected to "use data to construct reasonable explanations" in third through fifth grades, but no guidance is provided as to what constitutes a "reasonable" explanation at that level of schooling. In the same vein, students in higher grades are asked to "design and conduct appropriate types of scientific investigations."

At other points, expectations for student performance in this realm seem far too ambitious. For example, the core curriculum for sixth through eighth grades explains:

> **Scientific literacy also includes the ability to search for and assess the relevance and credibility of scientific information found in various print and electronic media. (grades 6-8)**

The corresponding "expected performance" column asks students to "read, interpret, and examine the credibility of scientific claims in different sources of information." Such ability is anything but common, even among professionals. For school science, aspiration is one thing; practical expectation, the most important element of a learning standard, is quite another.

Note, too, that—perhaps because of their overall brevity—Connecticut's inquiry and methodology standards make no mention whatsoever of the history of science.

Physical Science

Much of the content included in the Connecticut standards is covered with adequate depth and rigor. In addition, the grade-level expectations often helpfully build upon the standards provided in the curriculum framework. For instance, a second-grade standard explains that "solids tend to maintain their own shapes, while liquids tend to assume the shapes of their containers, and gases fill their containers fully." The related expectation asks students to:

> **Compare and contrast the properties that distinguish solids, liquids, and gases.**
>
> **Classify objects and materials according to their state of matter.**
>
> **Measure and compare the sizes of different solids.**
>
> **Measure and compare the volume of a liquid poured into different containers.**
>
> **Design a fair test to compare the flow rates of different liquids and granular solids. (grade 2)**

Similarly, in fourth grade, students are introduced to electromagnetism with a fine series of standards, some of which are:

> **Predict whether diagrammed circuit configurations will light a bulb.**
>
> **Develop a method for testing conductivity, and analyze data to generalize about which materials are good electrical conductors and which are good insulators.**
>
> **Observe magnetic effects associated with electricity and investigate factors that affect the strength of an electromagnet. (grade 4)**

Other times, however, the standards introduce errors or are too vague to guide rigorous curriculum and instruction. For example, fifth-grade students are asked to "explain that all visible objects are reflecting some light to the human eye." Of course, this is not necessarily true since there *are* self-luminous objects.

In eighth grade, students are asked to:

> **Assess in writing the relationship between an object's mass and its inertia when at rest and in motion. (grade 8)**

What the student is actually expected to do and say here is a mystery.

High School Physics

Connecticut's high school physics standards are generally demanding, though the presentation is confusing and disorganized. This is unsurprising, considering that all high school physics content is compressed into fewer than two pages of standards.

That said, simple mathematical expressions are used whenever appropriate. For example, Newton's laws of motion are dealt with in a systematic and straightforward fashion:

> **When forces are balanced, no acceleration occurs; thus an object continues to move at a constant speed or stays at rest.**
>
> **The law *F* = *ma* is used to solve motion problems that involve constant forces.**
>
> **When one object exerts a force on a second object, the second object always exerts a force of equal magnitude and in the opposite direction.**
>
> **Applying a force to an object perpendicular to the direction of its motion causes the object to change direction. (high school physics)**

And though it is brief, the coverage of heat and thermodynamics is among the best we have seen in terms of clarity and completeness:

> **Heat flow and work are two forms of energy transfer between systems.**
>
> **The work done by a heat engine that is working in a cycle is the difference between the heat flow into the engine at high temperature and the heat flow out at a lower temperature.**
>
> **The internal energy of an object includes the energy of random motion of the object's atoms and molecules. The greater the temperature of the object, the greater the energy of motion of the atoms and molecules that make up the object.**
>
> **Most processes tend to decrease the order of a system over time, so that energy levels eventually are distributed more uniformly. (high school physics)**

The coverage of energy and momentum, waves, and electromagnetism is presented in a similarly brief but cogent fashion. Missing, however, is pretty much all of modern physics.

High School Chemistry

The Connecticut chemistry standards are generally succinct and clearly written, touching upon a good deal of essential content. Some of it, including rates of reaction and chemical bonding, is covered well, as in the following:

> **Salt crystals, such as NaCl, are repeating patterns of positive and negative ions held together by electrostatic attraction. (high school chemistry)**

Unfortunately, the standards are not always worded as specifically or completely as this example, and important related material is often missing entirely. For example, one standard gives the definition of equilibrium, but mentions nothing else, not even Le Châtelier's principle.

A set of standards deals with moles, but stoichiometry of both chemical formulas and balanced equations are omitted. Another standard declares that "electronegativity and ionization energy are related to bond formation," but neglects to include *how* they are related.

Even more troubling, several major topics are missing entirely. These include solutions, oxidation/reduction reactions, acid/base chemistry, gases, and spectra/electron transition connections.

Earth and Space Science

The coverage of earth and space science is quite broad, but with a mix of rigorous and inadequate standards. On the high side are some beautifully written standards, such as this one:

> **The properties of rocks and minerals can be explained based on the physical and chemical conditions in which they were formed, including plate tectonic processes. (high school earth science)**

Still, a few topics are weak or completely missing. Fossils are never mentioned in the earth science material (although there is a brief mention in biology), nor are methods of absolute and relative dating of rocks.

Other essential topics are present, such as plate tectonics, earthquakes, and volcanoes, but the coverage is spotty. And sometimes a standard is too vague to be useful. Sixth graders, for example, are asked to "observe, analyze and record the unique physical and chemical properties of water." This statement is both unclear (water has many special properties; to which is Connecticut referring?) and too advanced for the grade level (the underlying theory is more appropriate for high school).

The rock cycle is not mentioned by name, and the details of rock formation that are implied are probably too advanced for the level at which they are presented. For example:

> **Observe and analyze rock properties (e.g., crystal size or layers) to infer the conditions under which the rock was formed. (grade 3)**

Extra-solar-system astronomy and cosmology are treated at the high school level clearly and logically, but too briefly. The standards ask for evidence for important theories such as the Big Bang, but said theories are not described.

Life Science

From Kindergarten through eighth grade, Connecticut's life science standards are adequate, but a few key topics are absent. For instance, there isn't an appropriate early introduction to Mendelian genetics and the existence, nature, and action of genes.

Curious inconsistencies also appear. For example, in fifth grade, sophisticated concepts and assignments are put forward, like "explore factors that affect human reaction time" and "describe the properties of different materials and the structures in the human eye that enable humans to perceive color." Yet students will have been taught nothing about cells, neurons, membranes, channels, receptors, and other necessary concepts and thus will lack the background to meet any such requirement. They don't even hear about cells until seventh grade.

The high school biology course is also superficial, with vague coverage of meiosis, cell structure, DNA, and most other topics.

Despite a good, early introduction to the idea of adaptation, the standards through eighth grade ignore other key ideas of evolutionary biology. At the high school level, evolution is again treated oddly. We're told about natural selection, genetic drift, and geographic isolation, but there's nothing about common ancestry, the more than three billion years of life's evolution, and so on. The unit ends with, "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" (high school biology). But we're not told how long ago that was.

Taken together, these inadequacies push Connecticut's average score down to a four out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

Connecticut's science standards are generally clear and well written, and for the most part, the content is logically organized and presented. As noted above, the standards introduce sufficient science content (with a few exceptions), and the grade-level expectations usefully specify how student mastery should be assessed and demonstrated.

There are exceptions. Some standards are vague, speaking around the necessary content instead of addressing it head-on. In the following eighth-grade standard, for example, it would be better to ask students to discuss the inverse-square nature of the gravitational force, rather than:

> **Relate the strength of gravitational force between two objects to their mass and the distance between the centers of the two objects and provide examples. (grade 8)**

Likewise, other standards speak around mathematical expressions, leaving the reader to parse through convoluted text.

> **Express mathematically how the mass of an object and the force acting on it affect its acceleration. (grade 8)**

Why not demystify this and ask students simply to understand the common expression, $F = ma$?

Overall, the Constitution State provides students and teachers with a well outlined and logically ordered set of standards, but the potential for excellence exists. The vagueness and unnecessarily complex text pushes Connecticut down to a score of two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

Comparison Review of Connecticut's 2009 and Updated 2010 Grade-level Expectations

Documents Compared

Connecticut Prekindergarten–Grade 8 Science Curriculum Standards Including Grade-Level Expectations. March 2009. Accessed from: http://www.groton.k12.ct.us/cms/lib2/CT01001200/Centricity/Domain/47/PK8_sciencecurriculumstandards2009.pdf

Prekindergarten–Grade 8 Curriculum Standards and Assessment Expectations: Science. 2010. Accessed from: http://www.sde.ct.gov/sde/lib/sde/pdf/curriculum/science/pk8_science_curriculumstandards2011.pdf

Overview

When our expert reviewers began analyzing the standards in late 2010, the Connecticut science standards were comprised of three documents: a 2005 *Curriculum Framework*, a 2005 *K-10 Content Matrix*, and a 2009 *Grade-Level Expectations* document. Since then, however, the state has adopted an updated 2010 *Grade-Level Expectations* document. While our reviewers evaluated the 2009 *Grade-Level Expectations* document in their formal review, in order to fairly assess the most recent Connecticut standards, we have included a comparison review of the updated 2010 document below.

Comparison: 2009 to 2010 Grade-Level Expectations

Though both the 2009 and the 2010 versions of the Connecticut preK-8 grade-level expectations generally cover the same material (and are, in fact, both based on the 2005 framework document reviewed above), the writers have added a section of "grade-level concepts" in the 2010 version. These concepts are an expansion of the grade-level expectations, explaining what students should "understand" (in addition to the expectations, which explain what students "should be able to" do).

Overall, the addition of these grade-level concepts is a mixed bag. In some instances, they provide otherwise-lacking depth and clarity to the standards. In the "heredity and evolution" section, for example, the 2010 document provides a solid explanation of heredity that was absent from the 2009 version. Likewise, units are added to one of the seventh-grade physical science standards, supplying helpful detail: "Work (measured in joules) is calculated by multiplying the force (measured in newtons) times the distance (measured in meters)..."

Further, the terse earth and space science standard, "Investigate and determine how glaciers form and affect the earth's surface as they change over time," gets expanded to the much more thorough:

> **Glaciers form in areas where annual snowfall is greater than the seasonal melt, resulting in a gradual build-up of snow and ice from one season to the next.**
>
> **Glaciers increase and decrease in size over long periods of time, depending on variations in Earth's climate.**
>
> **Glaciers move slowly, spreading outward across a region or moving down a slope.**
>
> **Moving glaciers reshape the land beneath them by scraping, carving, transporting and depositing soil and rock.**
>
> **Glacial landforms have identifiable shapes. Connecticut's landscape provides many examples of glacial movement and deposition. (grade 7)**

In other places, however, the "concepts" oversimplify standards or, worse, introduce errors, as in the following earth and space science standard:

> **All rocks are made of materials called minerals that have properties that may… (grade 3)**

In fact, all rocks are *not* made of minerals. And,

> **Earth's crust is broken into different "tectonic plates" that float on molten rock and move very slowly. Continental drift is driven by convection currents in the hot liquid mantle beneath the crust. (grade 7)**

This is a jarring misstep: Plates are made of lithosphere, not just crust. And lithosphere consists of the entire crust plus a little of the *solid* mantle. Almost the entire mantle is solid, not molten, though it does undergo slow convection. This is an important scientific point.

The Bottom Line

The 2010 *Curriculum Standards* admirably expand upon some key concepts that were shallowly presented in the 2009 document. However, they also introduce a number of generalizations and errors into the standards. On the whole, these additions even out; our final grade for Connecticut remains the same.

SCIENCE

Delaware

GRADE	SCORES		TOTAL SCORE
C	Content and Rigor	3/7	5/10
	Clarity and Specificity	2/3	

REPORT CARD

Content & Rigor	**3.2**
Scientific Inquiry & Methodology	2
Physical Science	5
Physics	0
Chemistry	0
Earth & Space Science	5
Life Science	7
Clarity & Specificity	**2.4**

Average numerical evaluations

Document(s) Reviewed

- *Delaware Prioritized Science Standards*. 2005-06. Accessed from: http://www.doe.k12.de.us/infosuites/staff/ci/content_areas/science.shtml
- *Delaware Science Content Standards Clarification Document*. 2006. Accessed from: http://www.doe.k12.de.us/infosuites/staff/ci/content_areas/files/science/ClarifyingtheScienceContentStandards.pdf

Overview

The Delaware science standards are generally robust, detailed, and thoughtful, and they present critical information clearly, with a minimum of jargon. Unfortunately, not all subjects are equally well covered; the document is uneven and its overall organization is somewhat cumbersome.

Organization of the Standards

The Delaware science standards are divided into eight "prioritized standards" (more commonly called strands): nature and application of science and technology, materials and their properties, energy and its effects, earth in space, earth's dynamic systems, life processes, diversity and continuity of living things, and ecology. For each strand, the state provides a series of "essential questions" and "enduring understandings," which are common across grade levels and which are meant to define the "big ideas" that students should learn. For example, in the strand covering nature and application of science and technology, three essential questions ask: "What makes a question scientific?" "What constitutes evidence?" and "When do you know when you have enough evidence?" A series of indicators is then provided for each group of essential questions at each of four grade bands: K-3, 4-5, 6-8, and 9-12. Finally, grade-specific standards are provided for all grades, K-12.

In addition, the state provides a second document that presents only essential questions, enduring understandings, and indicators by strand. While the grade-specific standards are not included in this document, its purpose is to prioritize the indicators as "essential," "important," or "compact." (Only the essential and important standards are assessed by the state.)

Content and Rigor

The Delaware standards have the potential for excellence, as shown in their virtually flawless handling of life sciences. Unfortunately, the confusing presentation—coupled with standards that are overly broad, omit essential content, or are impossible to achieve at the required grade level—detracts from their overall quality and rigor.

Scientific Inquiry and Methodology

The scientific inquiry and methodology standards are generally well written and they increase in rigor and complexity from grade span to grade span. In addition, the standards deal admirably with the practicalities of the laboratory experience, demanding attention to precision and accuracy. Take, for example, the following high school indicator:

> **Be able to: Collect accurate and precise data through the selection and use of tools and technologies appropriate to the investigations. Display and organize data through the use of tables, diagrams, graphs, and other organizers that allow analysis and comparison with known information and allow for replication of results. (grades 9-12)**

Delaware also makes a clear distinction between what students are asked to "understand" and what they are asked to be able to do.

That said, there are two significant drawbacks. The first is that the standards claim, "as the body of scientific knowledge grows, the boundaries between individual disciplines diminish." While interdisciplinary study has become popular, it relies on deep comprehension and mastery of discipline-specific content.

Second, the Delaware inquiry standards are not well integrated with content. Take, for example, the following:

> **Understand that: In communicating and defending the results of scientific inquiry, arguments must be logical and demonstrate connections between natural phenomena, investigations, and the historical *body of scientific knowledge*. (emphasis added)**

> **Be able to: Communicate and defend the results of scientific investigations using logical arguments and connections with the known *body of scientific information*. (emphasis added) (grades 9-12)**

While the standards mention linking the process standards to the "body of scientific knowledge," there are content gaps (discussed in greater detail below) that would sometimes make it difficult for students to associate the results of their investigations with historical science knowledge as the standards demand.

Physical Science/High School Physics/High School Chemistry

Through ninth grade, the physical science standards are generally detailed, though the division of content among the standards is odd. Standard Two, titled "materials and their properties," is primarily devoted to presenting chemistry content. Standard Three, titled "energy and its effects," primarily presents physics content. While not incorrect, the terminology is peculiar.

The high school standards suffer from three serious problems:

First, physics and chemistry are not treated as independent courses. Rather, standards are presented together and scattered across two strands, making it difficult to piece together what, precisely, students should know and be able to do in which subject in which year.

The order of the high school physics standards is also confusing, as if the writers took paragraphs from a physics text, shuffled them at random, added a few paragraphs about chemistry, and re-stacked them. And while the grade-level expectations are somewhat less muddled, they still confuse more than they enlighten.

Second, too many standards are overly broad, asking either too much or too little of students. For instance, an eleventh-grade standard asks students to:

> **Construct models or diagrams (Lewis dot structures, ball and stick models, or other models) of common compounds and molecules (i.e., NaCl, SiO_2, O_2, H_2, CO_2) and distinguish between ionically and covalently bonded compounds. Based on the location of their component elements on the periodic table, explain the elements tendency [*sic*] to transfer or share electrons. (grade 11)**

That is a big order for a single expectation, and one that covers an unrealistically large chunk of a high school chemistry course.

Yet another standard asks students to:

> **Construct a solubility curve based on data collected. Describe solubility and saturation point using the particle model. (grade 7)**

But constructing a solubility curve involves time-consuming lab work and assumes the ability to control temperature fairly well. Is this doable? And what aspects of solubility and saturation is the student expected to "describe" here?

Third, while some standards ask the unattainable, others arbitrarily hold students back from learning grade-appropriate content. For instance, the standards sedulously avoid using the words atom and molecule until the ninth grade, which leads to the awkward use of such imprecise terms as "particle model."

And the Delaware standards repeat an unintentional scientific fraud that is far too common in science standards:

> **Conduct investigations to demonstrate the process of diffusion. Use the particle model to describe the movement of materials from an area of higher concentration to an area of lower concentration. (grade 7)**

What is intended and widely used as a demonstration of diffusion—in which a drop of colored water is placed in a tank of apparently still water—is misleading, because the observed effect is really due to residual currents and uncontrollable convection. Diffusion in solids, which is easier to control, is difficult or impossible to demonstrate at this level due to the equipment required.

Finally, some very important topics are missing from the chemistry material for grades nine through twelve. Among these are the mole concept, stoichiometry, chemical formulas, and carbon chemistry. The ideal gas law is not mentioned by name, although one standard weakly hints at its existence.

Earth and Space Science

The presentation of important earth and space science material is generally excellent. For instance, in grades six through eight, the standards explain that:

> **Constructive processes that build up the land and the destructive processes of weathering and erosion shape and reshape the land surface. The height of Earth landforms is a result of the difference between the rate of uplift and the rate of erosion at a particular location. (grades 6-8)**

That is perhaps the best interpretation and explanation of this idea in any state standard.

The properties of water are similarly well-expressed:

> **Use a model or a diagram to explain water's properties (e.g., density, polarity, hydrogen bonding, boiling point, cohesion, and adhesion) in the three states of matter. Cite specific examples of how water's properties are important (i.e., water as the "universal [solvent]"). (grade 9)**

And the discussion of polymer chemistry is unusual and highly desirable—perhaps owing to the looming presence of DuPont in the state.

Some important topics are, however, glossed over or omitted entirely. For instance, except for a brief mention in ninth grade, plate tectonics receives scant attention. And there is no mention of important concepts such as the greenhouse effect, the solar cycle, earthquakes and measuring, relative or absolute dating, or astronomical units.

Life Science

The life science material is concise and accurate, and contains all the important concepts and facts a high school graduate should learn. The content is divided among three strands—life processes, diversity and continuity of living things, and ecology—and while it would be preferable to organize the standards addressing this related content together, the development of the content doesn't suffer here the way it does in other areas of science.

Overall, the standards are clear and well-developed. For example, the reproduction, heredity, and development subtopic begins in Kindergarten and continues through third grade with observations of similarities and differences between parent and offspring. It moves to an in-depth analysis of these patterns for plants in fourth through sixth grades. It gives a good general overview of asexual versus sexual reproduction in sixth through eighth grades, with fertilization and egg development, chromosomes and DNA, and chromosome number. Then, in high school, there's a lucid series of specific units on DNA replication, mutation, meiosis, and the relationship of meiosis and heredity patterns.

Evolution is treated thoroughly and the standards make clear its role as the basic organizing principle of the life sciences. Beginning at the earliest grades, simple ideas are set forth and then systematically elaborated.

This combination of strengths and weaknesses earns Delaware an average score of three out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

Most of the Delaware standards are clearly written and free from distracting jargon. In addition, the state sets clear and unambiguous priorities by clearly labeling the indicators that will be assessed by the state and by indicating which of those assessed standards is most important.

Unfortunately, the organization and presentation of the content is often confusing. Delaware has made the regrettable decision to eschew studying separate areas of science individually, preferring instead an "integrated approach" that scatters discipline-specific content across several strands. For instance, high school chemistry and physics content can be found in two strands—"materials and their properties" and "energy and its effects"—making it nearly impossible to piece together a comprehensive and rigorous high school chemistry or physics course. While organizing the standards in this way is never ideal, it has a particularly deleterious effect on the standards for high school physics and chemistry.

Taken together, these elements earn the First State a score of two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

District of Columbia

GRADE	SCORES		TOTAL SCORE
A	Content and Rigor	7/7	10/10
	Clarity and Specificity	3/3	

REPORT CARD

Content & Rigor	**6.7**
Scientific Inquiry & Methodology	5
Physical Science	7
Physics	7
Chemistry	7
Earth & Space Science	7
Life Science	7
Clarity & Specificity	**2.6**

Average numerical evaluations

Document(s) Reviewed

▶ *D.C. Learning Standards: Science.* 2006 (Grades 5 and 8, and Biology updated 2010). Accessed from: http://dcps.dc.gov/DCPS/In+the+Classroom/What+Students+Are+Learning/What+your+child+is+learning+and+expected+to+know+in+grades+K-12#0

Overview

The District of Columbia's science standards are among the best we have seen; they are excellent across the board. The one consistent drawback is the inclusion of "examples" that are meant to suggest activities that will help students master the standards. These examples—specifically at the high school level—are often ill-conceived and could distract educators from the otherwise outstanding material.

Organization of the Standards

Grade-specific science standards are presented for each grade, K-8. At the high school level, course-specific (rather than grade-specific) standards are presented for earth science, biology, chemistry, physics, and environmental science.

The K-4 standards are divided into five strands: scientific thinking and inquiry, science and technology, earth science, physical science, and life science. The standards for grades 5-8 are also divided into strands, but these differ based on the grade level, such as "the solar system" in sixth grade and "energy and waves" in eighth grade. Each strand is described by a "broad concept." For instance, the broad concept for the solar system in sixth grade reads:

> **Astronomy and planetary exploration reveal the structure and scale of the solar system.**

The high school course-specific standards are presented in a parallel manner. For all grades and subjects, strands are then divided into standards, which are listed along with examples that suggest student activities.

Content and Rigor

The D.C. standards are generally clear and rigorous, with content that progresses appropriately through the grades. Science standards in the District are comparable to those from California; both are stellar and either could serve as a national example of excellence. Interestingly, though, the D.C. standards are far more succinct than the California expectations. Yet each covers virtually all of the essential K-12 science content effectively—proving that it's possible (if difficult) to pull off both brevity and comprehensiveness.

Scientific Inquiry and Methodology

The scientific inquiry and methodology standards are generally clear and appropriately rigorous. Throughout, it is noted that "scientific progress is made by asking relevant questions and conducting careful investigations." Students in early grades are encouraged to ask, "How do you know?" in "appropriate situations" and to "attempt reasonable answers when others ask the same question." They are asked to "identify better reasons for believing something" than acceptance of the *status quo* and to "question claims based on vague attributes or on authority...or based on statements made by celebrities or others outside the area of their particular expertise." These goals continue in the higher grades, where students are asked to consider sample sizes, control groups, biased sampling, and analogy. Though not explicitly tied to content, if taken seriously, these standards could turn D.C. schools into a veritable wellspring of scientific and analytical thinkers!

History of science receives a brief nod in the preamble to the eighth-grade standards. Problematically, only pioneers of physics, cosmology, and "current atomic theory" merit a mention—as if pioneers in other fields are not worth referencing.

Physical Science

As is conventional, the physical science standards for Kindergarten through eighth grade include both physics and chemistry. The development of the physics part is clear and logical. For instance, in third grade, students are instructed to:

- **Recognize that energy is needed to carry out almost any kind of change;**
- **Describe basic forms of energy, including mechanical (kinetic and potential), light, sound, heat, chemical, nuclear, and electrical; and**
- **Recognize that energy can be transformed from one form to another. (grade 3)**

By eighth grade, they are expected to be able to:

- **Explain how energy is the ability to do work and is measured in joules;**
- **Describe kinetic energy as the energy of motion (e.g., a rolling ball), and potential energy as the energy of position or configuration (e.g., a raised object or a compressed spring); and**
- **Recognize and describe that energy is a property of many systems and can take the forms of mechanical motion, gravitational energy, the energy of electrostatic and magnetostatic fields, sound, heat, and light (electromagnetic field energy). (grade 8)**

These examples typify the systematic way in which content builds from grade to grade. Students can acquire a thorough background, preparing them well for the high school level courses.

The chemistry section is equally as rigorous, with atoms, molecules, and ions receiving especially strong coverage:

> **Recognize that all matter is made of small particles called atoms, which are too small to see with our eyes; describe how atoms may combine to form molecules or crystalline solids (compounds). (grade 5)**
>
> **Describe how the atoms, molecules, or ions comprising an object are in constant individual motion, and explain how their average motional (kinetic) energy determines the temperature of the object, and how the strength of the forces between them determines the state of matter at that temperature. (grade 8)**

High School Physics

The high school physics standards are excellent. Students are asked, for example, to:

> **Recognize that when a net force, F, acts through a distance, Δx, on an object of mass, m, which is initially at rest, work, $W = F\Delta x$, is done on the object; the object acquires a velocity, v, and a kinetic energy, $K = \frac{1}{2} mv^2 = W = F\,\Delta x$. (high school physics)**

This definition of kinetic energy in terms of the work-energy theorem is exemplary. Similarly, heat and thermodynamics are very well covered, as demonstrated by the following:

- **Recognize that heat flow and work are two forms of energy transfer between a system and its surroundings.**
- **Describe and measure that the change ΔU in the internal energy of a system is equal to the sum of the heat flow, Q, into the system and the work, W, done on the system: $\Delta U = Q + W$ (first law of thermodynamics).**
- **Describe and measure the work, W, done by a heat engine as the difference between the heat flow, Q_{in}, into the engine at high temperature and the heat flow, Q_{out}, out at a lower temperature: $W = Q_{in} - Q_{out}$. (high school physics)**

This is just the beginning of a series of eighteen standards that lays out the subject of thermodynamics in rigorous, logical, and clear fashion. Other areas of physics are comparably well covered.

The one flaw in these otherwise exemplary standards is that the "examples" given by the District are often silly. Here, as just one example, is what students are to do to understand the concept of entropy:

> **Students build a tower from dominoes or cards and examine the tendency of those systems toward greater disorder. They discuss the energy that would have to be used to prevent that disorder (e.g., using glue, sealing the tower in a vacuum, etc.). (high school physics)**

Sounds like a lot of fun, but it's hard to see how the students' understanding of entropy (defined as $S = Q/T$) will be enriched. To make matters still sillier, one wonders how the students will quantify the energy it takes to use glue, or how a house of cards will become more stable in a vacuum.

High School Chemistry

The District of Columbia's chemistry standards are excellent and cover all of the essential content. Take, for example, the exposition of acid-base chemistry:

> **Broad Concept: Acids, bases, and salts are three classes of compounds that form ions in water solutions. As a basis for understanding this concept,**
>
> **Students:**
>
> - **Explain that strong acids (and bases) fully dissociate and that weak acids (and bases) partially dissociate.**
> - **Define pH as the negative of the logarithm of the hydrogen (hydronium) ion concentration, and calculate pH from concentration data.**
> - **Illustrate and explain the pH scale to characterize acid and base solutions: Neutral solutions have pH 7, acids are less than 7, and bases are greater than 7.**
> - **Describe the observable properties of acids, bases, and salt solutions.**
> - **Explain the Arrhenius theory of acids and bases: An acid donates hydrogen ions (hydronium) and a base donates hydroxide ions to a water solution.**
> - **Explain the Brønsted-Lowry theory of acids and bases: An acid is a hydrogen ion (proton) donor, and a base is a hydrogen ion (proton) acceptor. (high school chemistry)**

This is as clear as it is precise.

Unfortunately, coupled with these excellent standards are a series of inane, confusing, or plainly wrong "examples." As impressive as the District's chemistry standards are, their examples are equally as appalling, as in the following:

> **Students conduct a titration experiment involving an acid and a base (vinegar and ammonia) using phenolphthalein as an indicator, and they relate it to a human condition, such as heartburn, which is associated with acid indigestion and sour stomach that requires the intake of an antacid for relief. (high school chemistry)**

Titration is a useful exercise, but the implication that the human stomach is normally neutral (pH 7.0) is far from the truth.

Another example:

> **Students determine the molar mass of 0.650 g of O_2 gas in 100.0 mL at STP.**

The writers of these examples—who could not possibly have been the same people to author the first-rate chemistry standards—seem unaware of the fact that no calculations are necessary for this. The molar mass of O_2 gas is 32 g/mole.

Earth and Space Science

As with the other content areas, the coverage of earth and space sciences is excellent across all grade levels. The treatment of astronomy is particularly strong. For example, students are asked to:

> **Observe how telescopes are used both to magnify images of distant objects in the sky, including the moon and the planets, and to gather enough light from very dim objects to make them visible. … Observe and describe that stars vary in size, but they are so far away that they look like points of light. (grade 5)**

This may be the only standard across the board that makes explicit the fact that while planets can be magnified by telescopes, stars are so distant that they cannot be magnified, and the function of the telescope is to gather more light.

Sixth grade features an elegant link between both thinking about planetary evolution in terms of sedimentary rocks and the findings of fossils in these strata, and then segues into biological evolution:

> **Explain how physical evidence, such as fossils and surface features of glaciation, supports detailed explanations of how Earth's surface has evolved over geologic time. (grade 6)**
>
> **Observe and explain that fossils provide evidence of how life and environmental conditions have changed. (grade 6)**

But again, the fine exposition is occasionally marred by examples that don't match the rigor of the material. For instance, in fourth grade, following the broad concept "energy and matter have multiple forms and can be changed from one form to another," comes:

> **Students take an 'energy' journey. They pretend they are photons of light that come from the sun, onto a plant, eaten by a dinosaur, which was eaten by another dinosaur. They explain their "energy" journey into forming molecules that made the dinosaur live, move, die, decompose, and reform into a fossil fuel. (grade 4)**

Oil comes from dinosaurs only in 1970s Chevron cartoon commercials. What will students say about the transformation of their photons to bonds in carbon chains?

Similarly, in sixth grade, students are asked to:

> **Measure the latent heat of water by taking the temperature of ice as it melts to water and water as it boils. Students relate this information to recent data on the suspected effects of global warming on glaciers. (grade 6)**

Students won't see any temperature change during the phase change; they would need some sort of calorimeter. They could notice that heat is being absorbed without a temperature change, which doesn't measure the latent heat but suggests it exists.

Life Science

The District of Columbia's life science standards are thorough, well developed, and appropriately rigorous. They could easily serve as a model for other states. Even the examples (criticized in other disciplines) are well handled, especially in the early grades.

One noteworthy example, from fourth grade, is the "broad concept" of the various mechanisms human beings employ to combat disease. Through nine well-ordered steps, students are taught the basics of the immune system, the nature of pathogens, and the importance of vaccines. None of this is over the head of a fourth grader, yet something this sophisticated and interesting is not often presented, even in high school.

Seventh grade covers biology at a level often found in high school standards. As with the earlier example about human defenses, the consideration of evolution is thorough and sophisticated.

High school biology is still more sophisticated, yet totally accessible to students who have had the grade-by-grade preparation outlined in the document. It begins with biochemistry, which few states do, and provides a thorough presentation of cell biology, genetics, evolution, physiology, and ecology.

Clear, rigorous, and comprehensive, the D.C. standards could easily stand as a national model to guide curriculum and instruction from Kindergarten through high school. The most significant flaw is the inclusion of poor support examples at the high school level. Because all of the critical content is covered—and covered well—by the standards, the District earns a seven out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The D.C. science standards are clear, succinct, and specific. They could easily guide rigorous curriculum and assessment development across all grades, from Kindergarten through high school.

As mentioned above, the District also provides "examples" that are meant to describe instructional activities that can help students master particular concepts. From Kindergarten through seventh grade, these examples often describe fruitful student activities (eighth grade offers no examples). Take, for instance, the following:

> **Students discuss the turtles, finches, and lizards unique to each of the Galapagos Islands and relate these phenomena to Darwin's natural selection. (grade 7)**
>
> **Students design and build a sundial (with support from the teacher) and use it to determine the time of day. They explore how accurate it is over time and determine the conditions under which the sundial does and does not work. (grade 3)**
>
> **Students observe and sketch crystalline structures of common minerals, such as quartz (resistant to weathering), mica (breaks down into thin, flexible shiny sheets), and calcite (soft mineral), and list the chemical compositions of each. (grade 6)**

Unfortunately, the high school examples (as discussed above) are far inferior, often bordering on the absurd.

Fortunately, the flaws are limited to the high school examples, meaning that the District scores a perfect three out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Florida

GRADE	SCORES		TOTAL SCORE
C	Content and Rigor	3/7	5/10
	Clarity and Specificity*	2/3	

REPORT CARD

Content & Rigor	**2.8**
Scientific Inquiry & Methodology	4
Physical Science	3
Physics	0
Chemistry	0
Earth & Space Science	5
Life Science	5
Clarity & Specificity*	**2.0**

Average numerical evaluations

Document(s) Reviewed

- *Next Generation Sunshine State Standards: Science*. 2008. Accessed from: http://www.floridastandards.org/Standards/FLStandardSearch.aspx

* After publication of this review, we realized that we double-faulted Florida for its failure to delineate specific standards for high school physics and chemistry (docking the state in both "content and rigor" and "clarity and specificity.") Upon further reflection, comparison of the standards against our rubric, and comparison to our review of other states' standards, we concluded that the Florida standards deserve a two out of three (rather than their initial one out of three) for clarity and specificity. This review reflects this change.

Overview

Florida's standards evoke a split personality. The document starts out well at the primary level, but in the higher grades it weakens into poor organization, ambiguous statements, and basic errors. One has the impression that the writers were pushing the limits of their scientific expertise at the higher grades. Taken as a whole, the document does not provide a solid foundation for a rigorous K-12 science curriculum.

Organization of the Standards

The Sunshine State standards for grades K-8 are divided first by grade level. They are then presented through a series of eighteen "Big Ideas" (like "changes in matter" and "earth and space in time"), which are further explained by a set of two to three descriptors each. All Big Ideas do not appear at every grade, but for those that do appear, grade-specific benchmarks are provided. Finally, a "depth of knowledge" indicator is attached to each benchmark to explain its "cognitive complexity."

The high school standards are broken down first into a series of "bodies of knowledge": life science, physical science, earth and space science, and nature of science. Within each body of knowledge is a set of "standards" (much like the Big Ideas in the K-8 standards), with benchmarks and "depth of knowledge" ratings linked to these standards.

Content and Rigor

Florida's science content presents a landscape of peaks and valleys, with uneven treatment both between and within disciplines. Life science and earth and space science are the best of the bunch, and manage to touch on most—but by no means all—of the critical content. Their presentation of the material also is fairly consistent throughout the grade levels. The same cannot be said for the other disciplines, which tend to offer more rigorous content in the K-8 years but stumble badly in high school.

Scientific Inquiry and Methodology

The nature of science is addressed competently but uninspiringly under four of the state's fifteen Big Ideas. To their credit, the writers make it clear that there is no single scientific method and that the terms used by scientists (notably, *theory*) often differ in meaning from their everyday usage.

But the benchmarks are somewhat vague and offer little guidance about how the ideas might be articulated in the classroom. For example, sixth graders are expected to "distinguish science from other activities involving thought." By eighth grade, students will "distinguish between scientific and pseudoscientific ideas [and] discuss what characterizes science and its methods," and in high school, they will examine the difference between science and "other ways of knowing." There could be something of value here in the hands of a competent teacher, but as is too often the case, discussion of demarcation (i.e., the philosophical problem of distinguishing between science and other activities) can lead to oversimplification and confusion. If this activity is to be carried out in the classroom, many teachers will need more help than the standards provide.

Physical Science/High School Physics/High School Chemistry

In many areas, the physical science standards get off on the wrong foot due to confusing or even erroneous Big Ideas. For instance, a descriptor under Big Idea 13 tells students that "it takes energy to change the motion of objects," which is not quite true. Consider a perfectly elastic collision of a Superball (or, for that matter, a gas molecule) with a wall. The ball changes direction but there is no change in energy.

Similarly, another descriptor of Big Idea 13 states that "energy change is understood in terms of forces—pushes or pulls." This statement is bound to confuse because, while there is certainly a connection between energy and force, this is not the most precise way to explain it.

Also, in fourth grade, two benchmarks that address heat flow are listed under a Big Idea that addresses waves. In fifth grade, two benchmarks that concern electric current flow are listed under that same Big Idea. Sadly, none of these is a wave phenomenon, and the standards that follow them are therefore a confused mess.

Further, students are asked to "describe heat as the energy transferred by convection, conduction, and radiation, and explain the connection of heat to change in temperature or states of matter" (high school physical science). But that doesn't define heat at all; it is no more illuminating than if one were to write "define money as the stuff transferred by sales, loans, and gifts." And the standard asking students to "relate temperature to the average molecular kinetic energy" (high school physical science) marks the sole appearance of kinetic theory—but the statement is in fact a consequence of the theory, which is never adumbrated.

Not surprisingly, there is a gratuitous reference to entropy that no one will understand and whose sole purpose is to place the readers in awe of the writers. As the reader will see in too many other state reviews, the very powerful and useful—but highly abstract—concept of entropy is often degraded to nothing more than a buzzword thrown around when those who do not understand it wish to impress the *polloi*. In this it is similar to the use of the term *quantum* by medical quacks.

The standards also suffer from internal inconsistencies. For instance, a descriptor of Big Idea 8 explains that, because the concepts of weight and mass "are complicated and potentially confusing to elementary students...the more familiar term 'weight' is recommended for use to stand for both mass and weight in grades K-5. By grades 6-8, students are expected to understand the distinction...and use [the terms] appropriately." But, in fourth grade, the state includes two standards that contradict this directive:

> **Measure and compare objects and materials based on their physical properties including: mass, shape, volume, color, hardness, texture, odor, taste, attraction to magnets. (grade 4)**
>
> **Explore the Law of Conservation of Mass by demonstrating that the mass of a whole object is always the same as the sum of the masses of its parts. (grade 4)**

To compound the confusion, the first explicit treatment of mass doesn't come until eighth grade.

Still, there are also some instances of appropriately rigorous content. In second grade we have:

> **Measure and compare the volume of liquids using containers of various shapes and sizes. (grade 2)**

This is an important point; younger children do not automatically make the abstraction that allows them to understand that the volume of a sample of liquid, for instance, is independent of the size and shape of the vessel that contains it. But Karplus showed, many years ago, that Kindergartners are ready for this concept, so perhaps it should be introduced earlier.

Finally, while sixth graders receive an estimable qualitative overview of the laws of gravitation and dynamics, this auspicious beginning is squandered in the higher grades. At the high school level, all we find is a fuzzy command to "interpret and apply Newton's three laws of motion," and then "develop logical connections through physical principles, including Kepler's and Newton's laws about the relationships and the effects of Earth, Moon, and Sun on each other." That comprises about four chapters in a typical textbook.

With no outline of a college prepatory chemistry course outside of the physical science material, the treatment of chemistry is weak throughout. Atomic models are not mentioned by name, though they are hinted at in the following high school physical science benchmark: "Explore the scientific theory of atoms (also known as atomic theory) by describing changes in the atomic model over time and why those changes were necessitated by experimental evidence." There is no mention of atomic spectra, spectroscopy, or electron transitions. Indeed, there is no mention of electrons at all prior to high school.

Chemical bonding is barely included, as a small part of the encyclopedic Standard 8B: "Atoms bond with each other to form compounds." Missing is the requirement for students to know ionic, covalent, and metallic bonding. Hydrogen bonds do appear (along with van der Waals forces), where they are explicitly distinguished from "bonding forces holding compounds together." The problem is that the standards do not clearly explain the nature of the interactions that hold atoms together in molecules and those that keep molecules themselves together—for example, the distinction between the forces at work in crystals or metals and the weaker attractions of, say, the hydrogen bonds that allow water molecules to become a liquid and a solid.

Earth and Space Science

Florida's treatment of earth and space science is fairly broad, but the coverage can be uneven and somewhat lacking in the detail necessary to insure proper depth of treatment. The early grades fare better than high school.

The topics that receive heavy emphasis are treated crisply, even elegantly. The eighth-grade astronomy standards, for example, are ambitious in introducing topics typically relegated to the high school level (when not all students take the earth and space science courses):

> **Distinguish the hierarchical relationships between planets and other astronomical bodies relative to solar system, galaxy, and universe, including distance, size, and composition. (grade 8)**

> **Create models of solar properties including: rotation, structure of the Sun, convection, sunspots, solar flares, and prominences. (grade 8)**

Other topics are glossed over or omitted entirely. The entire treatment of earthquakes and volcanoes, for example, is summed up with: "Recognize that heat flow and movement of material within Earth causes earthquakes and volcanic eruptions, and creates mountains and ocean basins" and "Explore the scientific theory of plate tectonics by describing how the movement of Earth's crustal plates causes both slow and rapid changes in Earth's surface, including volcanic eruptions, earthquakes, and mountain building" (grade 7). That's it.

Further, the treatment of plate tectonics is weak; the evidence leading to the development of this important twentieth-century theory is absent, as are the major details of the process itself.

The study of rocks begins in second grade with: "Recognize that Earth is made up of rocks. Rocks come in many sizes and shapes." But size and shape are the least useful observations that might be used to identify rocks, and certainly their least interesting properties. Fortunately, this coverage improves in later grades:

> **Identify the physical properties of common earth-forming minerals, including hardness, color, luster, cleavage, and streak color, and recognize the role of minerals in the formation of rocks. (grade 4)**

> **Identify the patterns within the rock cycle and relate them to surface events (weathering and erosion) and sub-surface events (plate tectonics and mountain building). (grade 7)**

In high school, the content offered is somewhat less helpful, providing more generalities than clear content expectations. For example, the study of stars starts out nicely in eighth grade:

> **Describe and classify specific physical properties of stars: apparent magnitude (brightness), temperature (color), size, and luminosity (absolute brightness). (grade 8)**

But the continuation of the topic in high school leaves some of the details to the reader:

> **Describe and predict how the initial mass of a star determines its evolution. (high school earth and space science)**

And the important topic of the greenhouse effect and its possible contribution to global climate change is reduced to a phrase in a standard so broad it could form the basis for an entire course:

> **Discuss the large-scale environmental impacts resulting from human activity, including waste spills, oil spills,**

> **runoff, greenhouse gases, ozone depletion, and surface and groundwater pollution. (high school earth and space science)**

The Florida earth and space science standards aren't bad, but some extra work could make them excellent.

Life Science

The Kindergarten through eighth-grade sequence provides good coverage of basic materials in the life sciences. Evolution is treated straightforwardly and in good detail. The topic is introduced as a principle in sixth grade, though the only specifics at that level address taxonomic classification. Still, even this initial treatment constitutes a decent beginning for this grade level.

At times, the treatment of life sciences is more thorough, if a bit lopsided. For example, Big Idea 14 is called "organization and development of living organisms," but it says nothing about embryos or development. Instead, it heavily stresses physiology, including bones, ureters, and the nervous system.

Evolution, on the other hand, is very well covered. Take, for example, the following:

> **Explain how the scientific theory of evolution is supported by the fossil record, comparative anatomy, comparative embryology, biogeography, molecular biology, and observed evolutionary change. (high school life science)**

> **Describe the conditions required for natural selection, including: overproduction of offspring, inherited variation, and the struggle to survive, which result in differential reproductive success. (high school life science)**

> **Discuss mechanisms of evolutionary change other than natural selection such as genetic drift and gene flow. (high school life science)**

Even human evolution is treated—a rarity in state science standards:

> **Identify basic trends in hominid evolution from early ancestors six million years ago to modern humans, including brain size, jaw size, language, and manufacture of tools. Discuss specific fossil hominids and what they show about human evolution. (high school life science)**

Barely a handful of states tackle human evolution in their standards, bolstering the life science score of the Sunshine State's standards. Still, omissions in other key areas keep these standards from receiving top marks in this discipline.

Taken together, the bright spots are overshadowed by the numerous gaps, omissions, and errors, thus earning the Sunshine State a three out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Florida standards are reasonably specific and present much clear, appropriately rigorous content. Take, for example, the following high school standard, which also exemplifies the strength of Florida's evolution coverage:

> **Describe the conditions required for natural selection, including: overproduction of offspring, inherited variation, and the struggle to survive, which result in differential reproductive success. (high school life science)**

Unfortunately, as noted at the outset, the high school standards are marred by a lack of organization, where content is often poorly sequenced and introduced out of context. This failing leads—perhaps inevitably—to detailed statements that are isolated and confused.

The standards also occasionally veer into the incomprehensible. An egregious example appears in one of the descriptors of Big Idea 2: "Scientific knowledge is based on empirical evidence, and is appropriate for understanding the natural world, but it provides only a limited understanding of the supernatural, aesthetic, or other ways of knowing, such as art, philosophy, or religion." What could this mean? Can we acquire even a limited understanding of the supernatural by means of scientific inquiry? Intelligent design, maybe?

Fortunately, these drawbacks are isolated, earning Florida an average score of two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Georgia

GRADE	SCORES		TOTAL SCORE
C	Content and Rigor	4/7	6/10
	Clarity and Specificity	2/3	

REPORT CARD

Content & Rigor	**4.2**
Scientific Inquiry & Methodology	5
Physical Science	4
Physics	2
Chemistry	3
Earth & Space Science	5
Life Science	6
Clarity & Specificity	**1.8**

Average numerical evaluations

Overview

The extraordinary unevenness of the Georgia standards reflects the disorganization of the parts. Some areas are strong and some adequate, while others lag badly. Although the end product is mediocre, better editing and a bit more attention to detail could significantly improve the standards.

Organization of the Standards

Georgia presents its science learning expectations by grade for K-8 and by course for high school. Content standards and "characteristics" (or inquiry) standards are presented for each grade and course. Grades K-5 each cover earth, life, and physical sciences. Sixth grade focuses exclusively on earth science, seventh grade on life science, and eighth grade on physical science.

At the high school level, the Georgia standards offer a bewilderingly large number of courses. In addition to the traditional biology, chemistry, and physics courses, there are astronomy, botany, earth systems, ecology, entomology, environmental science, epidemiology, forensic science, geology, human anatomy and physiology, meteorology, microbiology, oceanography, physical science, and zoology. As these courses fall outside the conventional, much broader core science curriculum, and as we have no idea when and how these myriad specialized courses are worked into students' learning plans, we have focused this review solely on the four core subjects.

The Peach State also presents a series of framework documents, one for each grade, K-8, and for physics, chemistry, biology, and physical science in high school. Within each of these documents is a strange mixture of classroom activities, lesson plans, common misconceptions, and key questions. The presentation within these documents is so sketchy, and the organization so chaotic, that a full evaluation is impossible, if not inappropriate. We therefore limit our discussion to the standards documents.

Content and Rigor

Georgia has produced a frustratingly spotty set of standards that range from excellent (life science) to pretty bad (physics and chemistry). When good, the material is well written, concrete, and thorough, with ambitious but not unreasonable expectations for what students ought to know, in both the lower and upper grades. Unfortunately,

Document(s) Reviewed

- *Georgia Science Standards*. 2004-2009. Accessed from: https://www.georgiastandards.org/standards/Pages/BrowseStandards/ScienceStandards.aspx such moments are not the norm. In too many instances, the material is sloppily presented, unfocused, or poorly supported.

Scientific Inquiry and Methodology

The Georgia standards contain good, clear statements on process. For example, in fifth grade: “Similar scientific investigations seldom produce exactly the same results, which may differ due to unexpected differences in what is being investigated, unrecognized differences in the methods or circumstances of the investigation, or observational uncertainties.” Well put.

Physical Science

The physical science standards are decidedly mixed. Some content is covered with depth and rigor. For example, the first-grade handling of light, sound, and magnetism is quite good. The standards take note of the fact that magnetic force is not blocked by paper, for example. Second grade introduces energy, but never deals with the question (tricky at this level) of what energy is. In third grade, heat is introduced nicely, and magnetism (introduced two grades earlier) is expanded. The introduction in fourth grade of optics—including mirrors, lenses, and prisms—is excellent.

Two specific examples will suffice to show how very good the standards can be. In eighth grade:

> **Students will have the computation and estimation skills necessary for analyzing data and following scientific explanations.**
>
> **a. Analyze scientific data by using, interpreting, and comparing numbers in several equivalent forms, such as integers, fractions, decimals, and percents.**
>
> **b. Find the mean, median, and mode and use them to analyze a set of scientific data.**
>
> **c. Apply the metric system to scientific investigations that include metric to metric conversions (i.e., centimeters to meters).**
>
> **d. Decide what degree of precision is adequate, and round off appropriately.**
>
> **e. Address the relationship between accuracy and precision.**
>
> **f. Use ratios and proportions, including constant rates, in appropriate problems. (grade 8)**

And at the high school level:

> **Students will explore the nature of matter, its classifications, and its system for naming types of matter.**
>
> **a. Calculate density when given a means to determine a substance’s mass and volume.**
>
> **b. Predict formulas for stable binary ionic compounds based on balance of charges.**
>
> **c. Use IUPAC nomenclature for transition between chemical names and chemical formulas of**
>
> - **binary ionic compounds (containing representative elements).**
> - **binary covalent compounds (i.e., carbon dioxide, carbon tetrachloride).**
>
> **d. Demonstrate the Law of Conservation of Matter in a chemical reaction.**
>
> **e. Apply the Law of Conservation of Matter by balancing the following types of chemical equations:**
>
> - **Synthesis**
> - **Decomposition**
> - **Single Replacement**
> - **Double Replacement. (high school physical science)**

Sadly, as often as they are this good, the standards fail to outline sufficiently the content that students need to learn. For instance, gravitation is introduced in Kindergarten, but in a way that is likely to confuse more than clarify. Specifically, students are asked to “observe and communicate effects of gravity on objects,” and to:

> **Recognize that some things, such as airplanes and birds, are in the sky, but return to earth.**
>
> **Recognize that the sun, moon, and stars are in the sky, but don’t come down.**
>
> **Explain why a book does not fall down if it is placed on a table, but will fall down if it is dropped. (Kindergarten)**

Is the Kindergartner to conclude that gravity affects books always, airplanes sometimes, but stars never? In the child’s first encounter with a phenomenon, it is best to present the simple and obvious first, and then move on to the complications.

Then in fifth grade, students are presented with this statement: “In simple terms, a chemical change cannot be reversed and a physical change can.” Clearly, however, neither part of this statement is true. The melting of butter is an irreversible physical change, while the chemical reaction $2Hg + O_2 \leftrightarrow 2HgO$ is readily reversible.

And here is the sum total of the eighth-grade coverage of mechanics:

> **Students will investigate relationship between force, mass, and the motion of objects.**
>
> **a. Determine the relationship between velocity and acceleration.**
>
> **b. Demonstrate the effect of balanced and unbalanced forces on an object in terms of gravity, inertia, and friction.**
>
> **c. Demonstrate the effect of simple machines (lever, inclined plane, pulley, wedge, screw, and wheel and axle) on work. (grade 8)**

High School Physics

The high school physics course is divided into five major concepts/skills: kinematics, energy and its transformations, electricity, magnetism, and wave properties. To the physicist's eye, this is a very strange—and illogical—division. Kinematics without dynamics is pointless; electricity and magnetism belong together (as indeed they are in Georgia's standards for the lower grades); and heat and thermodynamics are missing, as are optics and pretty much all of modern physics.

Getting down to detail, Newtonian dynamics is telescoped into a few words; nuclear fission and fusion are introduced without preparation, under an "energy" standard that *precedes* the standard containing the basics of the work-energy theorem, energy conservation, and the mere mention of potential energy. The rest is mere chaos, ending with a section devoted to relativity.

High School Chemistry

Only about a page and a half of the standards are dedicated to actual chemistry content; predictably, much essential content is missing. For instance, there is nothing on the important topic of gases. Nor is there anything about Lewis dot structures or how they can help predict the shape and polarity of molecules. The topic of chemical bonding is reduced to "compare and contrast types of chemical bonds (i.e., ionic, covalent)." Hydrogen bonding and metallic bonding are completely missing. Also missing is any mention of oxidation/reduction. The important topic of chemical equilibrium (and Le Châtelier's principle) is reduced to a meaningless standard asking students to "explain the role of Equilibrium in chemical reactions." There is no mention of carbon (organic) chemistry, and the periodic table section is inadequate. If basic topics like groups (chemical families), periods, metallic, nonmetallic, and metalloid regions, and so forth, are not taught in primary and middle school grades, then they need to be addressed in high school chemistry. (High school physical science contains some topics, like specific heat and conductivity of solutions, that should have been included in chemistry.)

Earth and Space Science

The earth and space standards taken alone (that is, ignoring the framework documents) are well written, reasonably ambitious, and complete. The standards for Kindergarten through eighth grade have some weaknesses in rocks and minerals and details of plate tectonics. The high school material is contained in a large collection of high school courses. Though none of the courses related to earth and space material addressed all our suggested content, each was well written and could lead to an interesting and serious semester course. It is not clear, however, which or how many students would take those courses.

Georgia offers some particularly nicely written entries, for instance:

> **Students will model the position and motion of the earth in the solar system and will explain the role of relative position and motion in determining sequence of the phases of the moon. (grade 4)**
>
> **Demonstrate the relative size and order from the sun of the planets in the solar system. (grade 4)**
>
> **Compare and contrast the Earth's crust, mantle, and core including temperature, density, and composition. (grade 6)**
>
> **Relate the Nature of Science to the progression of basic historical scientific models (geocentric, heliocentric) as they describe our solar system, and the Big Bang as it describes the formation of the universe. (grade 6)**

Each of these examples displays good knowledge of the subject and how students might demonstrate deep understanding. The entry on the layers of the solid earth calls out the specific properties of each layer that sixth graders should be able to understand. Modeling the geometry of moon phases is a great way to demonstrate an understanding of motions in the solar system. Relating the progression of historical ideas about important models is a sophisticated way to address the science behind current understandings.

Life Science

Unlike the other disciplines, the presentation of life science material is quite good, typified by the systematic treatment of evolution in middle school. It begins with a fine general statement in the benchmarks covering sixth through eighth grades:

> **During middle school, several lines of evidence are further developed. The fossil evidence can be expanded beyond extinctions and survivals to the notion of biological history. Sedimentation of rock can be brought in to show relative age. However, actual age, which requires an understanding of isotopic dating techniques, should wait until high school, when students learn about the structure of atoms. Breeding experiments can illustrate the heritability of traits and the effects of selection. (grades 6-8)**

Further, Georgia's standards are one of the few to discuss Darwin prior to the high school level:

> **Explain that physical characteristics of organisms have changed over successive generations (e.g., Darwin's finches and peppered moths of Manchester).**
>
> **Describe ways in which species on earth have evolved due to natural selection.**
>
> **Trace evidence that the fossil record found in sedimentary rock provides evidence for the long history of changing life forms. (grade 7)**

High school biology coverage is sound and generally complete, tackling organelles, mitosis and meiosis, Mendel's Law, and photosynthesis well (to name a few subjects). The standards' focus on the cell and molecular-level content offers thoughtful overviews and good specific examples. Unfortunately, the strong seventh-grade coverage of evolution is not carried along to high school, where coverage of evolution is missing such key concepts as DNA or the sequences of amino acids—though it does include coverage of molecular and anatomical evidence.

In the end, these peaks and valleys leave Georgia with a four out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

As is the case with the content and rigor of Georgia's standards, much inconsistency of quality is seen in terms of clarity and specificity. When they are good, the Georgia standards offer information accurately and in simple prose. We have cited several examples of this fine work above. But when they are bad, they produce brief and vapid expressions, as in: "Explain the role of equilibrium in chemical reactions" (high school chemistry). More detail is ardently desired, yet none is forthcoming.

In some places, the standards' brevity leaves the reader confused, as in the following example:

> **Measure and calculate the magnitude of frictional forces and Newton's three Laws of Motion. (high school physics)**

This is both an illogical combination and a mighty tall order to compress all of Newton's laws (e.g., all of dynamics) into half of a fourteen-word statement. The result, of course, is neither clear nor specific. And then there's this:

> **Determine the heat capacity of a substance using mass, specific heat, and temperature. (high school physical science)**

The intent, doubtless, was something like, "Calculate the *quantity of heat absorbed or given out* by an object when its mass, specific heat, and temperature *change* are known." But as written, the passage is not only confusing, it's simply wrong.

These issues taint the otherwise straightforward Georgia standards, resulting in a score for the Peach State of two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

REPORT CARD

Content & Rigor	**3.3**
Scientific Inquiry & Methodology	2
Physical Science	5
Physics	2
Chemistry	5
Earth & Space Science	2
Life Science	4
Clarity & Specificity	**1.3**

Average numerical evaluations

SCIENCE

Hawaii

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	**3/7**	4/10
	Clarity and Specificity	**1/3**	

Overview

The Hawaii science standards are a case study in half-loaves and inconsistencies. At times the K-8 standards are reasonably rigorous and thorough. But the high school material in the Aloha State is woefully inadequate, including only rare islands of content floating in a sea of omission, confusion, and plain inaccuracy.

Organization of the Standards

Hawaii's science standards are presented in an online database that lists all standards by grade or course. For grades K-8, content and performance standards are divided into three strands: the scientific process; life and environmental science; and physical, earth, and space sciences. Each strand is then divided into two or three sub-strands (called standards) and finally into grade-specific benchmarks. In addition, for each benchmark the state provides a sample performance assessment and rubric that explain what student achievement would look like at each of four proficiency levels (advanced, proficient, partially proficient, and novice).

High school standards are similarly structured, but each high school course lists its own unique strands, in addition to course-specific benchmarks and performance assessments. Hawaii offers standards across eleven courses, including: physical science, biological science, earth space science, physics, chemistry, environmental science, marine science, plants and animals in Hawaii, human physiology, zoology, and botany.

In addition, Hawaii provides a *Curriculum Framework*, which offers additional information about how teachers might organize curriculum, assessment, and instruction.

Content and Rigor

The Hawaii science standards start out with clear, rigorous, and grade-appropriate statements; glaring content gaps and omissions become increasingly evident as the grade levels progress. The inadequacy of the writers' knowledge is distressingly evident in high school, when scientific content across nearly all disciplines is rife with misconceptions and errors. For physics in particular, the ignorance on display is shameful. Other disciplines, regrettably, fare little better.

Document(s) Reviewed

- *Hawaii Content and Performance Standards for Science*. 2007. Accessed from: http://standardstoolkit.k12.hi.us/index.html
- *Hawaii Curriculum Framework for Science*. 2008. Accessed from: http://165.248.30.40/hcpsv3/files/sc_122208_librarydocs_242.pdf

Scientific Inquiry and Methodology

The scientific inquiry and methodology standards are explained through two sub-strands of the scientific process strand: scientific investigation and nature of science. The latter is curiously defined as "understanding that science, technology, and society are interrelated." But the interpretation of this platitude is almost singularly concerned with a utilitarian view of techno-science with no mention of the historical development of science.

The benchmarks themselves are also problematic for two reasons. First, many are so brief that they fail to delineate the content that students must learn. For instance, second-grade students are asked to "develop predictions based on observations," and the standards indicate that this will be achieved by having the students make "predictions based on observations." Neither outlines what, precisely, students should know and be able to do, and the clarification unhelpfully conflates the goal with the method.

Second, there is little progression of content or rigor from grade to grade. For instance, in sixth grade, the state expects students to formulate a testable hypothesis and to "collect, display and analyze data." Then in seventh grade, students are asked to "design and safely conduct a scientific investigation to answer a question or test a hypothesis." Unfortunately, the seventh-grade benchmark does little more than combine the two sixth-grade benchmarks.

Physical Science

The physical science content is generally strong in the early grades. First graders are, for instance, expected to identify solids, liquids, and (perhaps ambitiously at this level) gases. At the same level, force and motion are appropriately introduced with the following expectation:

> **Describe how the motion of an object can be changed by force (push or pull).**
>
> - **The student: Explains the motion (change in speed and/or direction) of an object when he or she pushes or pulls that object. (grade 1)**

In third grade, students are asked to "define energy and explain that the sun produces energy in the form of light and heat." This is a good beginning, though (as is all too common) no definition of energy is either provided or suggested.

By sixth grade, however, the standards fail to include the requisite content that students would need to learn in order to accomplish the objectives listed. For instance, students are asked to describe "a variety of energy transformations (e.g., heat energy into mechanical energy; chemical energy into light energy; electrical energy into magnetic energy)." Unfortunately, the transformation of heat energy into mechanical energy involves heat engines, which require more detail than is given here. In addition, the last of the examples provided for this module is problematic; the writers likely didn't understand that the energy in the magnetic field around a current-carrying wire is not somehow converted from the energy required to keep the current flowing in the wire.

By high school, the content gaps become even greater. Take, for instance, the following:

> **Describe different examples of the concept of entropy.**
>
> - **The student: Describes different examples of the flow of energy coming from an energy source, demonstrating that while the total energy of the universe remains constant, matter tends to become steadily less ordered as various energy transfers occur. (high school physical science)**

Anyone who attempts to introduce the concept of entropy out of the blue, with no prior discussion of the laws of thermodynamics, succeeds only in demonstrating that he or she has no idea what entropy means.

Finally, the scope and sequence of material is often illogical. For instance, in the high school physical science course, students are asked to "describe the factors that affect the rate of chemical reactions." Unfortunately, there has been no prior discussion of what a chemical reaction is, or any examples of reactions. Illogically, that essential prerequisite content comes later. In this same course, the discussion of vectors, which is essential to the development of kinematics, is presented after Newton's laws, which have to do with dynamics. Fixing this glitch wouldn't be difficult, merely involving a swap in order, but the muddle speaks to the general lack of thought that went into creating this material.

High School Physics

The discussion of energy in the high school physics standards is fraught with problems. The treatment of the work-energy theorem (where, in fact, no mention of work occurs) and the items concerning energy are chaotic nonsense. At one point the student is expected to analyze an *inelastic* (i.e., non-energy-conserving) collision using energy conservation. Prior to the discussion of energy, however, there is no discussion of kinematics and dynamics (the logical first steps in any physics course) so that the abrupt presentation of kinetic energy as $\frac{1}{2} mv^2$ makes no sense at all.

High School Chemistry

Unlike physics, the high school chemistry standards are generally clear, thorough, and appropriately rigorous. They include such sophisticated tasks as balancing redox equations and calculating pH from the H^+ concentration. Unfortunately, some essential content is also missing, such as the Bohr and wave-mechanical models of the atom. Other concepts are introduced, but are not sufficiently defined or explained. Take, for example, this standard:

> **Apply gas laws to relationships between pressure, volume, and temperature of any amount of an ideal gas or any mixture of ideal gases using *PV = nRT*. (high school chemistry)**

Here, the ideal gas law is introduced concisely as an equation, but the standards never explicitly define the terms. In fact, while the quantities p, V, and T are implicitly defined, n (the number of moles), R (the universal gas constant), and the ideal gas itself are not.

Earth and Space Science

Hawaii's earth and space science content is particularly thin and underdeveloped, with but a few brighter spots here and there, including the standard asking students to describe "that the universe consists of billions of galaxies which are classified by shape and contain most of the visible mass of the universe" (grade 8). Likewise, high school students are asked to explain "how scientists use rock sequences, fossils, and radioactive dating to estimate the age of fossils and the age of Earth itself"—a solid request, albeit not perfectly worded (scientists use rock sequences to estimate the age of fossils as part of building a coherent story of the age of some rocks).

The Hawaii science standards make little use of the unique and interesting natural history of the islands themselves. The terms shield, basalt, and crater do not show up on a string search. The term magma comes up once in an eighth-grade standard asking students to "[describe] continental drift and how the Earth's crust is divided into plates that move on convection currents of magma in the mantle." But even this is incorrect, since the mantle is mostly solid rather than liquid magma. There are only two mentions of tsunamis. The first appears in a discussion of the effects of movements of crustal plates, and requires eighth-grade students to "[explain] the effects produced at each boundary (e.g., mountain building, earthquakes, tsunami), and the impact on society (e.g., natural disaster safety, building requirements)." (See the life science section of this state profile for the other occurrence of the word tsunami.) Though Hawaii is not at a plate boundary, it has a serious history of tsunami events; students should be asked to understand them.

The high school earth space science course presents an odd view of scientific theory and the current explanation for the origin of the universe. Say the standards: "Compare different theories concerning the formation of the universe," further explained in the sample performance assessment as: "The student: Compares the Big Bang Theory to another theory of the origin of the universe (includes supporting evidence for both theories and evidence that refutes the theories) and recommends which theory is more plausible." What other theory is to be considered? Religion or mythology aside, there are no other scientific theories for the origin of the universe that have not been abandoned because they do not account for observations. But this is the case for lots of abandoned theories (e.g., the caloric theory of heat or the phlogiston theory of chemical reactions); why choose cosmology for this exercise?

Life Science

Given the pedagogical opportunities presented by Hawaii's history of unique ecosystems largely overwhelmed by invasive species, the middling treatment of life science represents a missed opportunity. In the early grades, the content is thin and averse to specifics. In seventh grade, the notion of genes residing on chromosomes—and being responsible for heritable traits—appears, but there's nothing about what genes are and how they work. Fossils are also introduced in seventh grade as "providing evidence that life and environmental conditions have changed over time" but the standards say nothing about natural selection or common ancestry until high school.

There are misconceptions and howlers: Students, for example, are asked to explain "how organisms respond (e.g., some organisms adapt, some move out, others die) to changes in the physical environment, such as tsunamis and hurricanes" (grade 8). It's a little difficult to imagine organisms adapting quickly enough, or moving out quickly enough, to respond to a tsunami or a hurricane.

And there are errors, too: Sickle-cell and cystic fibrosis are cited as examples of chromosomal mutations, but in fact they are single-gene mutations.

With too many gaps and startling unevenness, Hawaii receives an average score of three out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

Getting from one end of the Hawaii standards to the other feels like a fruitless journey. There is some mention of important technical and scientific terms, but just as much unspecific muddle. The clarity of the material is eroded by poor grade-by-grade development and weak presentation of the sciences as logical, structured bodies of knowledge. Typos and sloppy writing abound, which further obscure the intended meaning of the standards in many places. The treatment of dynamics commits far too many of these sins, with content that is disorganized and out of sequence.

The state also provides a rubric meant to add clarity by defining student mastery of each standard at four levels of proficiency. Unfortunately, this rubric too often confuses rather than clarifies. Students in high school chemistry, for example, are asked to "calculate the number of moles needed to produce a given gas, volume, mass, and/or number of moles of a product given a chemical equation." What this means is impossible to discern.

Sadly, the rubric adds little value, differentiating between achievement levels only by saying that advanced students do so with "correct computations," proficient students with increasing errors, and novice students with "serious errors in computation." In no way does this help clarify what is expected of students or how content could be scaffolded across proficiency levels.

Taken together, these drawbacks earn the Hawaii standards an average score of one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Idaho

GRADE	SCORES		TOTAL SCORE
F	Content and Rigor	2/7	2/10
	Clarity and Specificity	0/3	

REPORT CARD

Content & Rigor	**1.5**
Scientific Inquiry & Methodology	2
Physical Science	1
Physics	0
Chemistry	4
Earth & Space Science	2
Life Science	0
Clarity & Specificity	**0.4**

Average numerical evaluations

Overview

The Idaho science standards contain precious little science. What little appears tends to be couched in broad generalities that fail to delineate what, precisely, students should know and be able to do. Making matters worse, the quality of the prose is so poor that parsing what the writers are trying to convey can be difficult. These failings make it impossible to imagine how the Idaho standards could serve as an adequate foundation for a workable K-12 science curriculum.

Organization of the Standards

The ordering of these standards is enigmatic. That is not surprising, perhaps, since properly presenting the tight structure of a particular area of science implies a reasonable depth of understanding of these structures—something not demonstrated in this document.

The K-6 standards are divided first into five "standards," more commonly thought of as strands: nature of science, physical science, biology, earth and space systems, personal and social perspectives, and technology. Each strand is then divided into a series of goals common to all grades and finally into a set of grade-specific "objectives," or standards.

Beginning in seventh grade, the standards are presented by course. Seventh grade is devoted entirely to biology. Then follow two courses slated for eighth/ninth grade: physics and chemistry, and earth science. We presume the courses based on these standards are taken one per grade, and that students could take either course in either grade, but the standards do not make this clear. A ninth/tenth-grade course covers high school biology, and an eleventh/twelfth-grade course is devoted to chemistry.

Finally, certain objectives also have "content limits," presumably to restrict the scope of items that may appear on the state test.

Content and Rigor

The Idaho standards are remarkable in their almost total disregard for the essential content necessary to educate children in the sciences. With the exception of earth and space sciences—exceptional only in juxtaposition to the rest—no discipline receives even remotely adequate coverage. Generally speaking, the quality of the

Document(s) Reviewed

- *Idaho Science Content Standards by Grade Level*. 2006. Accessed from: http://www.sde.idaho.gov/site/content_standards/science_standards.htm scientific content starts poorly in the primary grades and declines throughout each progressive grade level, as though the writers were grappling with the limits of their own knowledge of the subject matter.

Scientific Inquiry and Methodology

Idaho makes the unfortunate sacrifice of utility on the altar of brevity and vagueness, substituting wisps of fluff for meaningful content. Students are, for example, merely asked to "make observations," "use cooperation and interaction skills," "follow instructions," "follow multi-step instructions," "conduct scientific tests," "read and give multi-step instructions," and "read and follow technical instructions." There is no actual content in any of these broad generalities.

Physical Science/High School Physics

High school physics is not covered as a separate course. To the extent that it is present, it is under the heading of physical science.

The standards begin on a hopeful note, at least in the early grades. For example, in third grade we read: "Identify the physical properties of solids, liquids, and gases." This is followed in fourth grade by "describe the physical properties of solids, liquids, and gases," and in fifth grade with "compare the physical differences among solids, liquids, and gases." The associated fifth-grade content limit requires that "students will be able to recognize the differences in molecular distance between a solid, a liquid, and a gas, as well as differences in basic molecular motion."

Unfortunately, such bright spots are the exception. Too often, lofty goals are untethered to details. For instance, in high school, students are asked to do the following:

> **Describe the Kinetic Molecular Theory as it applies to phases of matter. (grades 11-12)**

But the mere mention of kinetic theory has no value as a stand-alone standard. What is intended here? And why are both of these important topics mentioned for the first time in high school?

High School Chemistry

The Gem State's high school chemistry standards address roughly half of our evaluation criteria, including the mole concept (and molarity), the connection between light and atomic structure, and the key concepts of kinetic molecular theory—all topics that many states ignore. Moreover, they include some important additional information, such as electron configurations; strong and weak electrolytes, and nonelectrolytes; and the Law of Definite Proportions.

Unfortunately, most of the content that is presented lacks necessary rigor or clarity, making it difficult to ascertain the actual content that is to be taught. Take, for example, the following expectation:

> **Distinguish the common theories defining acids and bases. (high school chemistry)**

This standard does not make clear what, precisely, the state expects students to know or be able to do.

Much important content is also missing, including: gases; specific mention of ionic, covalent, metallic, and hydrogen bonding; molecular shapes and polarities; oxidation/reduction reactions; and carbon chemistry.

Earth and Space Science

If the Idaho standards can be said to have a silver lining, it can be only in their treatment of earth and space sciences, which contains a few examples of thoughtfulness. Students in fourth grade, for example, are asked to "explain the effect of moon's gravity on Earth's tides," a quite reasonable and timely expectation. In eighth/ninth grade, students should know how to "identify methods used to estimate geologic time"—an important and useful objective that perhaps might have been introduced earlier but nevertheless is commendable.

Unfortunately, even here many important subjects are simply ignored or glossed over. Among those omitted topics are galaxies, plate tectonics, the properties of minerals and rocks, and fossils. Referenced only in passing are the Earth's layers (limited to a sixth-grade content limit and not to an objective itself), weather, climate (limited to the sixth-grade statement, "Explain the water cycle and its relationship to weather and climate"), and the rock cycle (mentioned with little detail in fifth grade.)

Life Science

The life science content is woefully inadequate. The full extent of the treatment of evolution, which comes in seventh grade, is this standard: "Describe how natural selection explains species change over time." That's it.

High school biology receives a similarly hasty sweep-over. The following standard in ninth/tenth grade represents the complete discussion of organelles: "Explain cell functions involving chemical reactions." The coverage of reproduction in those grades fits, implausibly, into thirteen words: "[Explain] how cells use DNA to store and use information for cell functions."

Further, biology cannot recover from unfortunate statements like this, from the third-grade standards: "Diagram the food web and explain how organisms both cooperate and compete in ecosystems." *The* "food web"?

Taken together, these failings earn Idaho an average score of two out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Idaho science standards are as poorly organized as they are vague and repetitious. This is particularly true for standards addressing scientific inquiry and methodology, where statements are repeated almost verbatim across grades.

And head-scratching confusion abounds. Students in sixth grade, for example, are asked to "define the properties of matter." Huh?

In eighth/ninth grade, students must somehow "describe the characteristics of isotopes" and "state the basic electrical properties of matter," but it's impossible to understand what, exactly, is expected here. Also in these grades, students are expected to "describe the relationships between magnetism and electricity." A mighty big order! We may take it for granted that these students won't be expected to expound on Maxwell's equations, foundations of electrodynamics, and electric circuits.

Even more perplexing, some of the standards—particularly in biology—veer suddenly from the excessively vague into the highly specific, with jarring effect. For instance, while the standards contain nothing in depth on genes, ninth/tenth-grade students are asked to "explain how selective expression of genes can produce specialized cells from a single cell."

Finally, the content limits, which are included to add clarity to the document, too often only add confusion. For instance, a particularly tortured fifth-grade content limit asks students to "recognize the change(s) in physical properties that take place when physical changes occur including ice melting into water and water being heated into steam and the reverse processes." Sadly, this wandering sentence is far from unique in the Idaho standards.

Certainly, this document is useless for all the purposes for which science standards are intended. As a result, the standards earn a pitiful average score of zero out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Illinois

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	3/7	4/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**3.0**
Scientific Inquiry & Methodology	7
Physical Science	2
Physics	0
Chemistry	0
Earth & Space Science	4
Life Science	5
Clarity & Specificity	**1.3**

Average numerical evaluations

Document(s) Reviewed[1]

- *Illinois Learning Standards: Goals 11, 12, 13*. 1997. Accessed from: http://www.isbe.state.il.us/ils/science/standards.htm
- *Illinois Classroom Assessments and Performance Descriptors*. 2002. Accessed from: http://www.isbe.state.il.us/ils/science/capd.htm
- *Illinois Assessment Frameworks*. 2004-2005. Accessed from: http://www.isbe.state.il.us/assessment/IAFIndex.htm

[1] Illinois's standards have not changed since Fordham's 2005 evaluation. However, the evaluation criteria used here have been updated and improved since 2005; also, in this report, we reviewed the assessment frameworks for the standards, something we did not do in 2005. (See Appendix A for document-selection methods and criteria used in this review.) These changes brought Illinois's final science grade from a B to a D. The complete 2005 review can be found here: http://www.edexcellence.net/publicationsissues/publications/sosscience05.html.

Overview

The Illinois science standards fail to provide the guidance necessary to ensure that students in the Land of Lincoln learn the critical K-12 science content they need to be college- and career-ready. Wild disorganization, poor writing, and illogical sequencing—compounded by critical content gaps and omissions—leave these standards significantly short of acceptable.

Organization of the Standards

Illinois's science standards are first articulated by three "goals": inquiry and design; concepts and principles; and science, technology, and society. For each goal, standards are provided for five vague grade bands: early elementary, late elementary, middle/junior high, early high school, and late high school.

The state also provides "expanded performance descriptors," which are meant to clarify the standards. Unfortunately, these descriptors are not explained by grade level, either. Instead, expectations of students must be fished out of a murky alphabet soup of "stages," A through J, which correspond loosely (but with much overlap) to grade levels. For example, stages A and B correspond to first grade; stages A, B, and C to second grade; stages B, C, and D to third grade; and so on. Stages I and J are both associated with grades eleven and twelve. For each of these expanded performance descriptors, both individual standards (different from those available through the goals documents) and "assessments" (which also read like standards) are available.

Finally, the *Illinois Science Assessment Framework* further organizes the goals and standards for the tested grades: four, seven, and eleven.

Content and Rigor

Illinois covers some content well—particularly in life science and earth and space science. But these highlights contrast sharply with the overwhelmingly inadequate treatment of the rest of the disciplines, which omit more essential content than they include.

Scientific Inquiry and Methodology

Illinois offers clear and well-articulated process standards that thoroughly outline what is expected of students and teachers. Process expectations are explicitly linked to content areas of the standards. Apart from the overuse of the term "brainstorming" as a desirable skill, there is nothing to find fault with here. Attention is paid to the historical and social aspects of science and technology; interestingly, students are asked to interview scientists about "how they address validity of scientific claims and theories and/or their understanding of scientific habits of mind (including sheer luck) and how they have been integral to their own research." All in all, an admirable job.

Physical Science/High School Physics/High School Chemistry

The treatment of physical science is a disaster from Kindergarten through twelfth grade. In the earlier grades, the biggest problems tend to involve a frustrating reliance on statements that are so broad as to be meaningless.

For instance, in the assessment framework we find this chain of expectations:

> **Understand that electrical energy can be converted to other types of energy such as heat, light, or mechanical energy. (grade 4)**
>
> **Understand that besides static electricity, there is also such a thing as current electricity. For example, given a battery, bulb, and wire, students will understand the proper configuration to make the bulb light. (grade 4)**

But this sequence is the reverse of the internal logic of the subject of electromagnetism. A bit later in the same document comes another jumble:

> **Understand that light travels at different speeds in different materials. Understand that this is why light refracts—or changes direction—namely because it goes from one material in which it moves at one speed into another material through which it moves at a different speed. (grade 7)**

Here the "explanation" in the second sentence is merely a reiteration of the first, and both are inadequate.

In the later grades, logical structure falls apart, with equally troubling consequences. By eleventh grade, for example, students should be ready for the rigorous definition of energy, beginning with the work-energy theorem, proceeding to kinetic energy and then to potential energy as the energy of configuration. In Illinois, however, they get this instead:

> **Understand that energy, defined somewhat circularly, is 'the ability to change matter,' or 'the ability to do work.' Understand that energy is defined by the way it is measured or quantified. Understand the difference between potential and kinetic energy. (grade 11)**

This passage is nonsense—and backwards, as well.

Mixed in with the vapid and nonsensical standards are statements that are simply wrong. Take, for example, the following expectation:

> **Graphing the temperature variations associated with phase changes of simple substances. (grades 4, 5, and 6)**

But when a sample of a substance, being subjected to heating or cooling, is going through a phase change, the temperature does *not* change.

None of the documents appear to make room for a separate section on high school physics.

While still inadequate, the coverage of critical chemistry content is marginally better than that of physics. In eleventh grade, for example, the standards begin with clearly written conceptual statements that thoroughly address related ideas. The section on kinetic molecular theory and gas behavior explains gas pressure and diffusion by considering molecular motion. Gas law relationships include the ideal gas law and related problem solving. Also mentioned are the specific STP conditions and the necessary temperature conversions between Celsius and Kelvin scales.

There is also good material on such significant matters as balancing chemical equations, and the mole is defined nicely with a connection between mass and number of atoms.

Still, the standards are plagued by the omission of great swaths of critical content as well as expectations that are presented with no internal logic. For instance, the standards never get to important topics like shape and polarity of molecules, stoichiometry, carbon chemistry, rates of reaction, and equilibrium. Those items that do exist are plagued by a variety of shortcomings, such as in the following passage:

> **Apply scientific inquiries or technological designs to explain chemical bonding and reactions, balancing chemical reactions using formulas and equations to quantify reaction masses, volumes and ratios, examining factors that affect capacity to react or rates (concentrations, pH, catalysts, molarity, temperature, etc.), or referencing the bonding potential and strengths within and between atoms and molecules. (grades 11 and 12)**

Concentrations, pH, and molarity are cited as separate factors affecting reaction rates. But molarity *is* the unit of concentration while pH *is* a measure of concentration; specifically, that of the hydronium ions. And significantly missing from the list of rate factors is the surface area of solids. As for the rest of this statement, it is as if a glossary of science words had been tossed into the air. After landing, the resulting random word patterns were used to complete this performance descriptor.

Earth and Space Science

On the positive side, the treatment of cosmology in the learning standards and assessment framework is solid, as the following examples illustrate:

> **Explain theories, past and present, for changes observed in the universe. (early high school)**

> **Describe the size and age of the universe and evaluate the supporting evidence (e.g., red-shift, Hubble's constant). (late high school)**

> **Know the theory that over 10 billion years ago the universe began in a huge expansion called the Big Bang. Understand that in this event, all matter, energy, space, and time were created as the universe expanded from a single point. Understand that one piece of evidence for this theory is the 3K background radiation. (grade 11)**

These standards are clear, accurate, and sufficiently rigorous. And the material covering Earth history is equally strong, as demonstrated by the following:

> **Understand that geologic layers and radioactive dating of rocks and meteorites provide evidence that the earth is about 4.6 billion years old, and that life has existed on Earth for over 3 billion years. Understand how to use a geologic time table. (grade 7)**

> **Understand that life on Earth has been changed by major catastrophes (e.g., the impacts of asteroids, volcanic eruptions). (grade 7)**

> **Understand that most scientists believe that the sun, the earth, and the rest of the solar system formed from a nebular cloud of dust and gas 4.6 billion years ago. (grade 11)**

"Most scientists believe" is a sop to creationists, but the statements are otherwise clear.

On the other hand, the standards themselves are too broad to offer much guidance. They rarely support the material in the assessment framework and leave teachers with minimal concrete guidance as to what students should know and be able to do. Consider, for example, the following learning standards, which ask that students:

> **Identify and explain natural cycles of the Earth's land, water, and atmospheric systems (e.g., rock cycle, water cycle, weather patterns). (late elementary)**

> **Analyze and explain large-scale dynamic forces, events, and processes that affect the Earth's land, water, and atmospheric systems (e.g., jetstream, hurricanes, plate tectonics). (middle/junior high school)**

> **Describe and explain short-term and long-term interactions of the Earth's components (e.g., earthquakes, types of erosion). (late elementary)**

> **Describe interactions between solid earth, oceans, atmosphere, and organisms that have resulted in ongoing changes of Earth (e.g., erosion, El Nino [*sic*]). (middle/junior high school)**

If not for the laudable content presented in the assessment framework, the Illinois earth and space science standards would be almost unsalvageable. Further, the convoluted organization of the standards among three disparate documents has a direct and strongly negative impact on the standards' overall rigor.

Life Science

Life science is the (relatively) high watermark for the Illinois standards. While by no means perfect—there is a curious absence of anything, at any grade level, on organ systems or physiology (muscles, nerves, digestion, etc.)—some of the material is laudably rigorous.

The assessment framework for grades four, seven, and eleven provides an excellent sequence pertaining to biochemistry, (molecular) genetics, and (molecular) cell biology that other states would do well to emulate. For example, in seventh grade, students are asked to understand mitosis and meiosis in considerable detail, as well as the concept that cells differentiate as they multiply in a zygote. In high school they learn that specialization of cells in multicellular organisms is usually due to different patterns of gene expression.

Surprisingly, although Illinois provides good coverage of evolution in grade seven and in high school, Illinois is one of the few states that still eschews the use of the word "evolution," misusing the euphemism "change over time" as a substitute:

> **Understand natural selection or *survival of the fittest*, and understand that *this is thought to be one of the explanations* how animals and plants *change over time***

> **and that it was the explanation given by *Charles Darwin*. (emphasis added) (grade 7)**

In spite of a glimmer of quality in life science, the overall rating can be no more than a three out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

Between the many overly broad statements and frequent head-scratching rambles, the Illinois standards rate poorly on clarity and specificity. However, scrutiny of a wide selection of individual items shows that the quality of the standards on these criteria varies significantly. Some are clear and specific, while others are so vague they are virtually meaningless.

The physical science material is perhaps the worst offender, rife with garbled, confusing, and plainly illogical writing. A few examples suffice to illustrate the problem:

> **Describe the effects of electromagnetic and nuclear forces including atomic and molecular bonding, capacitance, and nuclear reactions. (early high school)**

What a wild combination of unconnected ideas! It is as though one wrote: "Describe the effects of turkey and plumbing supply sales including supermarkets and convenience stores, banks, and the tax structure."

> **Identify the number of different kinds of elements in a chemical formula. (grade 7)**

What is a "kind of element" and how does one do this?

> **Identify the basic properties of acids and bases. Know the relationship between acids, bases, and indicators (e.g., blue litmus paper changes to red when placed in an acid). (grade 7)**

That's a tortured way of saying, "know that indicators turn different colors when exposed to acids and bases." Relationships are for psychologists, not hydrogen ions.

> **Know the laws of the conservation of matter and energy. (grade 7)**

Quite a bit for a single indicator—and that's only part of it.

> **Understand that density is mass per volume, and that what is denser than something else at the same volume will have more mass, but at the same mass it will have less volume. Understand that less dense bodies have greater buoyant force in water. (grade 7)**

Let's hope the same authors didn't write the English language arts standards.

The damage is not total, however. The content statements in the assessment framework are coherent, clear, literate, scholarly, specific, elegant, and sometimes superb. But these aren't enough to raise the average score for clarity and specificity above a lowly one out of three. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Indiana

GRADE	SCORES		TOTAL SCORE
A-	Content and Rigor	6/7	9/10
	Clarity and Specificity	3/3	

REPORT CARD

Content & Rigor	**6.2**
Scientific Inquiry & Methodology	7
Physical Science	5
Physics	5
Chemistry	7
Earth & Space Science	6
Life Science	7
Clarity & Specificity	**2.8**

Average numerical evaluations

Document(s) Reviewed

▶ *Indiana Academic Standards for Science.* 2010. Accessed from: http://dc.doe.in.gov/Standards/AcademicStandards/PrintLibrary/science.shtml

Overview

The Indiana science standards are clear and rigorous, with particular strength at the high school level in chemistry, earth and space science, and life science. The materials are occasionally marred by the omission of important content and a general lack of specificity that undermines their overall effectiveness. But even with these flaws, the document contains the fundamentals for a balanced, effective curriculum.

Organization of the Standards

Indiana presents grade-specific standards for grades K-8 and course-specific high school standards for Biology I, Chemistry I, Physics I, Earth and Space Science I, Integrated Chemistry-Physics, and Human Anatomy and Physiology.

At each grade level, K-8, the standards are divided first into strands. There are four strands in Kindergarten (nature of science, physical science, earth science, and life science), and five in grades 1-8 (nature of science; design process; physical science; earth science; life science; and science, technology, and engineering). At the high school level, the standards are organized similarly, except that benchmarks are presented by course, rather than by grade.

In addition, for grades 6-8 and high school, the state provides a "reading for literature in science" and "writing for literature in science" strand.

Content and Rigor

Indiana has a long history of producing very good science standards. This latest version is consistent with that laudable tradition. The document lays out key content in clear prose, building logically and effectively through advancing grade levels with refreshing precision. Expectations are both reasonable and rigorous.

Scientific Inquiry and Methodology

Indiana lays out a worthy set of process standards. Teachers are presented with principles that are meant to be "integrated into the curriculum along with the content standards on a daily basis." Generally these principles are clearly stated, although there is some regrettable reference to the nebulous act of "brainstorming" solutions to problems. Of particular note is how, in sixth grade and beyond, reading and writing for literacy in science is integrated into the classroom, emphasizing that "instruction in reading, writing, speaking, listening, and language" is not solely the province of the humanities instructor. The principles of literacy in science are clearly stated, appropriate, and should be adopted by other states.

Methodology is nicely integrated into the content matter, is presented at reasonable length and depth, and is never used as a hand-waving mechanism to hide the absence or paucity of content.

Physical Science

The physical science standards are generally clear, thorough, and appropriately rigorous. Take, for example, the following first-grade standard:

> **Experiment with simple methods for separating solids and liquids based on their physical properties. (grade 1)**

It's nice that this common first-grade task—distinguishing between solids and liquids—is couched in experimental terms.

Similarly, the following sixth-grade standards are strong:

> **Recognize that objects in motion have kinetic energy and objects at rest have potential energy.**
>
> **Describe with examples that potential energy exists in several different forms (e.g., gravitational potential energy, elastic potential energy and chemical potential energy).**
>
> **Compare and contrast potential and kinetic energy and how they can be transformed from one form to another.**
>
> **Explain that energy may be manifested as heat, light, electricity, mechanical motion, and sound and is often associated with chemical reactions. (grade 6)**

Unfortunately, the standards suffer from a few drawbacks. Energy is first defined in seventh grade only as "the capacity to do work," a fairly loose definition that belongs three or four grades earlier. By waiting so long to introduce energy and not treating it in more depth, the standards do not prepare students for later study. Complicating matters, the student is required in fourth grade to "provide evidence that heat and electricity are forms of energy," never having been provided with a clue as to what energy is, let alone how one would identify forms of it.

There are some other minor weaknesses. For instance, in third grade, students are asked to:

> **Investigate how the loudness and pitch of sound changes when the rate of vibrations changes. (grade 3)**

But the effect of "rate of vibrations" (i.e., frequency) on intensity is nonexistent, and its effect on the related physiological property pitch is a second-order effect far beyond the scope of third-grade studies.

High School Physics

Hurrah! The high school physics materials actually begin with kinematics and then follow up with dynamics before going on to other things. This is rare and laudable. It does give one pause, however, to see all of Newton's three laws (plus some other items such as free-body diagrams) shoehorned into one single high school standard.

The standards also address heat and thermodynamics in a logical way, even asking the student to derive the ideal gas law from the kinetic molecular model—although somehow the equation $pV = nRT$ never appears. Nor do the second law or heat engines.

Electricity and magnetism are introduced with the logical progression provided by Coulomb's law: electric field–electric potential–electric current. But after this good start, the integration of electricity and magnetism into electromagnetism is barely touched upon and neither Ampère's law nor Faraday's law appears.

High School Chemistry

Curricula based on the Indiana chemistry standards would prepare students reasonably well for a first-year college chemistry course. That said, there are some problems and deficiencies. Le Châtelier's principle, which describes the effects of a disturbance on a system in equilibrium, is missing, as are Lewis dot structures and molecular shapes and polarities.

Overall, however, these chemistry standards are extremely impressive and would serve as a worthy model for most other states. While many state standards documents do not mention calculations at all, Indiana presents more than ten chemistry standards that call for calculations and problem solving. These cover such diverse topics as percent composition, equation stoichiometry, gas laws, half-life, and calorimetry.

Curiously, the standards include expectations for a high school integrated chemistry and physics course. While it contains some good material, the content seems too rigorous for an eighth/ninth-grade physical science course. At the same time, it cannot carry the burden of the standard one-year high school chemistry and physics courses. These last two, in any case, have their own standards, both of which are good.

Earth and Space Science

The earth and space science standards are a pleasure to read, competently—often elegantly—written, and well organized. They develop a great deal of interesting content. For example, the following standards demonstrate how students are introduced to soils in first grade:

> **Observe and compare properties of sand, clay, silt, and organic matter. Look for evidence of sand, clay, silt, and organic matter as components of soil samples.**
>
> **Choose, test, and use tools to separate soil samples into component parts.**
>
> **Observe a variety of soil samples and describe in words and pictures the soil properties in terms of color, particle size and shape, texture, and recognizable living and nonliving items.**
>
> **Observe over time the effect of organisms like earthworms in the formation of soil from dead plants. Discuss the importance of earthworms in soil. (grade 1)**

These simple exercises are gradually built upon, so that by the time the student reaches fourth grade, they are expected to do the following:

> **Demonstrate and describe how smaller rocks come from the breakage and weathering of larger rocks in a process that occurs over a long period of time.**
>
> **Describe how wind, water, and glacial ice shape and reshape earth's land surface by eroding rock and soil in some areas and depositing them in other areas in a process that occurs over a long period of time.**
>
> **Describe how earthquakes, volcanoes, and landslides suddenly change the shape of the land. (grade 4)**

Other topics, such as solar system astronomy, are dealt with equally well.

Some important content is missing, particularly astronomical, tectonic, and climate detail in the elementary grades. But there is still plenty for a good elementary science program and the high school content borders on excellent. For instance, high school students are to learn about solar system formation, the Herzsprung-Russell diagram, Hubble's law and the Big Bang, and the general structure of the universe.

This is a thorough and systematic introduction to the essential concepts of cosmology.

Life Science

The life science material flows nicely and the concepts are well integrated. Here, for example, is the treatment of embryology in seventh grade:

> **Explain that after fertilization a small cluster of cells divides to form the basic tissues of an embryo and further develops into all the specialized tissues and organs within a multicellular organism. (grade 7)**

The material on heredity is also presented in depth at this level, asking students to "understand the relationship between deoxyribonucleic acid (DNA), genes, and chromosomes" (grade 8).

The terms evolution, natural selection, common ancestry, and so on are notable for their absence from Kindergarten through eighth grade. The most we get in eighth grade is:

> **Describe the effect of environmental changes on populations of organisms when their adaptive characteristics put them at a disadvantage for survival. Describe how extinction of a species can ultimately result from a disadvantage. (grade 8)**

By contrast, the coverage of evolution at the high school level is excellent.

Metabolism and photosynthesis are also covered in detail at the high school level, and there is a smooth continuation of embryology with the following:

> **Understand that most cells of a multicellular organism contain the same genes but develop from a single cell (e.g., a fertilized egg) in different ways due to differential gene expression. (Biology I)**

Heredity is covered equally well.

Many of the high school standards are particularly sophisticated, including:

> **Recognize that traits can be structural, physiological, or behavioral and can include readily observable characteristics at the organismal level or less recognizable features at the molecular and cellular level. (Biology I)**

Essentially all of the biology material pertinent to physiology is contained in the separate document on anatomy and physiology standards. While the material is excellent, this is presumably an add-on course, meaning that few students will learn this important segment of biology.

With a few exceptions, discussed above, the Indiana standards are rigorous and thorough, covering much of the critical K-12 science content. As a result, Indiana earns a six out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Indiana standards are presented in a clear and easy-to-follow outline. As an unintended consequence, the knowledgeable reader has no trouble spotting the gaps, discussed in detail above. But the expectations that are included are written in unambiguous language and are specific enough to support the development of a rigorous K-12 science curriculum. Consequently, Indiana earns an impressive average score of three out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Iowa

GRADE D

SCORES

Content and Rigor	**2/7**
Clarity and Specificity	**1/3**

TOTAL SCORE 3/10

REPORT CARD

Content & Rigor	**1.8**
Scientific Inquiry & Methodology	0
Physical Science	3
Physics	0
Chemistry	0
Earth & Space Science	3
Life Science	5
Clarity & Specificity	**1.1**

Average numerical evaluations

Document(s) Reviewed

- *Iowa Core Curriculum: K-12 Science.* 2007. Accessed from: http://educateiowa.gov/index.php?option=com_content&view=article&id=2330&Itemid=4342

Overview

Looking at the *Iowa Core Curriculum* for science is like trying to see through frosted glass. The paucity of detail, and the many moments of obscurity in the text, make it difficult and at times impossible to know precisely what is to be taught. What is clear, however, is that the standards do not contain the ingredients for a robust education in the sciences.

Organization of the Standards

The Iowa standards are divided into four content strands: science as inquiry, physical science, earth and space science, and life science. Within each strand, "essential concepts and/or skills" that students must master are presented in four bands: grades 9-12, grades 6-8, grades 3-5, and grades K-2 (presented in that order). Finally, the state provides an "illustration" of each essential concept and skill. These illustrations are drawn from the voguish *International Center for Leadership in Education (ICLE) Rigor and Relevance Framework* and its four pedagogical "Quadrants": Quadrant A–Assimilation, Quadrant B–Adaptation, Quadrant C–Acquisition, and Quadrant D–Application. The quadrants contain sample activities that teachers could use to teach the essential concept or skill, and the quadrants move from the least rigorous (Quadrant A) to the most rigorous (Quadrant D) (see Figure 1, from the high school earth and space science standards).

The state is careful to note that "the quadrants are samples, presented here to illustrate and clarify the expected level of rigor. They DO NOT constitute a curriculum nor will one set provide a sufficient opportunity for students to engage a big idea in science."

At the high school level, physical science is covered broadly; there is no separate coverage of physics or chemistry courses appropriate for these students. It is safe to assume, though, that the materials presented under the life science strand for grades 9-12 apply to a standard biology course.

Content and Rigor

Sloppy organization, vagueness, and lack of detail—this baleful trio characterizes the Iowa standards across all disciplines and grade levels.

Figure 1: Illustration of *Understand and apply knowledge of Geochemical cycles* in the ICLE's Rigor and Relevance Framework	
Quadrant C The carbon cycle is an important life supporting cycle. Some say the cycle has been shifted to an unbalanced system, one in which the shift has gone toward an overabundance of CO_2. Provide information to support or refute this belief.	**Quadrant D** You are a member of a business team charged with developing energy sources that will be used to decrease the emission of carbon dioxide. Respond to the following questions based on this scenario: What energy systems will you select as those to support for development? What are the pros and cons of each method? What are the short-term advantages and disadvantages of each? Long-term advantages/disadvantages? The feasibility of their uses by developed and developing nations?
Quadrant A Students are asked to use a textbook and/or the Internet to compile a list of elements and compounds (ex. water, nitrogen) that may be associated with cycles in the earth-ocean-atmosphere system. *Evolution and Equilibrium	**Quadrant B** Students are asked to choose either the nitrogen or the carbon cycle, draw and label the cycle and explain it to other students using the drawing as a visual aid. Students should be sure to point out the role that humans play in the cycle. *Evidence, Models, and Explanation

Scientific Inquiry and Methodology

The Iowa scientific inquiry and methodology standards constitute a single page ("Integrated Standards") that is functionally useless, providing no guidance or grade articulation. For example, the totality of the statement for "Science in Personal and Social Perspectives" reads, absurdly: "Make appropriate personal/lifestyle/technology choices, evaluate, observe, discuss/debate, recognize interactions and interdependencies at all levels, explain, describe environmental effects of public policy, choose appropriate course(s) of action." No further content, standards, or elaboration is provided.

Physical Science/High School Physics/High School Chemistry

The general disorganization of the Iowa standards is exacerbated by all-too-frequent errors that mar the document. This problem is particularly acute in the physical sciences.

Three examples, two concerning physics and one chemistry, will suffice. From physical science in high school: "The nuclear forces that hold the nucleus of an atom together, at nuclear distances, are usually stronger than the electric forces that would make it fly apart." A little thought reveals that the attractive nuclear forces must balance—not exceed—the repulsive electrostatic ones if the nucleus is to be stable.

Things go similarly awry when high school students receive the popular "rowdy raisins" demonstration—a bit tardily, as this typically comes around fifth grade. For this project, "students explain what they observe when a few raisins are dropped into a container full of a clear carbonated beverage and relate this phenomena to scuba diving. Why is rule number one in scuba diving that divers are NOT to hold their breath? What are the bends? What do the gas laws have to do with diving?"

These are excellent questions whose answers involve no little insight into the solubility of gases as a function of pressure as well as the physiological basis of the bends. But the behavior of the raisins has nothing to do with scuba diving. Their up-and-down motion is due entirely to the breaking off at the surface of bubbles nucleated on the fruit in the carbonated liquid.

Ionic, covalent, and polar covalent molecules crop up in both Quadrants B and D of the high school physical science standards. Here students are asked to use these terms to explain how the body absorbs vitamins and the ability of detergents to remove stains. Yet they have not yet learned about ions or polarity, among other key topics.

Earth and Space Science

There are a few rare bright spots in Iowa's coverage of earth and space science. The role of water as a solvent in geology is well presented in third through fifth grades, and the properties of soils are considered in a consistent manner.

But the flashes of light are eclipsed by numerous examples of topics that are mentioned but not described or explained in satisfactory detail. The history of the universe is raised but the body of evidence supporting this model is woefully insufficient. Relative and absolute dating are mentioned but there is no description of the processes. The layers of the earth get a dusting of attention—"the solid earth consists of layers including a lithosphere; a hot, convecting mantle and a dense metallic core" (grades 6-8)—but that's it.

Life Science

The content for life science in Kindergarten through fifth grade is very vague, and the content for sixth through eighth grades is not much better. That's not surprising, given how little ink the standards devote to the subject: two pages for Kindergarten through second grade, two pages for grades three through five, and three pages for grades six through eight. In contrast, the material we presume is intended for high school biology (though it is not so labeled) receives twenty pages. Up to the level of high school biology, the word evolution is nonexistent; there is just some gauzy stuff about biological adaptation.

Then comes the highly detailed high school biology course, where the content is generally sound, including excellent evolution material and even some human evolution. But here again, many of the items in the quadrants are obscure or difficult to perform. For example, measuring O_2 and CO_2 production requires elaborate equipment. Students and teachers receive little guidance for how to perform these activities.

The overall score for content and rigor is a sub-par two out of seven (see Appendix A: Methods, Criteria, and Grading Metric)—a mark that, given the occasional flashes of excellence, is even more disappointing for what might have been.

Clarity and Specificity

It's hard to decide if the *Iowa Core Curriculum: K-12 Science* is "not half bad" or just "half bad." On the plus side, the use of English is good and the document even contains the occasional "wow" moment. The discussion of water as a solvent in third through fifth grades is a nifty addition.

But the "essential concepts and/or skills" are often far too broad. The principles underlying them are sometimes "included but are not limited to"—an unhelpful construction, to say the least. Although the sample quadrants sometimes contain useful ideas and processes, these appear to be chosen more or less at random; they are not particularly useful for guiding the construction of a curriculum. For example, why should topics like electronic structure, electronegativity, and first ionization energy suddenly appear in a quadrant activity when they weren't even hinted at in the "essential concept and/or skill" statement? By the same token, one has to wonder what other important and required topics were left out because there are only four quadrants.

Confusingly, the standards are presented in reverse chronological order, so that the high school standards appear first. This idiosyncratic top-down ordering of materials (from high school down to Kindergarten) makes it difficult to trace the building of a concept from elementary beginnings to a sophisticated level.

Too often, students are to be asked unanswerable questions or given wildly challenging tasks. An example from life sciences: "If a characteristic is found in bacteria, fungi, pine trees, snakes, and humans, when did it most likely evolve?" The obvious answer is "when the last common ancestor of these organisms lived," but that is little better than a tautology.

Poor organization, vagueness, and lack of detail underlie the Iowa science standards, leaving them with a score of one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Kansas

GRADE	SCORES		TOTAL SCORE
B	Content and Rigor	5/7	7/10
	Clarity and Specificity	2/3	

REPORT CARD

Content & Rigor	**5.2**
Scientific Inquiry & Methodology	7
Physical Science	4
Physics	6
Chemistry	4
Earth & Space Science	3
Life Science	7
Clarity & Specificity	**1.8**

Average numerical evaluations

Overview

The Kansas science standards vary considerably in quality, both across the sciences and across grade levels. The life science and physics standards are generally clear and rigorous (with caveats). But standards covering chemistry are middling, and those for earth and space science are mediocre at best—in both subjects, much elementary-level material is deferred to high school and much high school-level material is missing. In life science, evolution is sidestepped or ignored until grades 8-12, where a brief but very good treatment appears. In the end, the standards present a decidedly mixed bag.

Organization of the Standards

The *Kansas Science Education Standards* are divided first into seven "standards" (more commonly denoted as strands): science as inquiry, physical science, life science, earth and space science, science and technology, science in personal and environmental perspectives, and history and nature of science. A series of "benchmarks" is provided for each of the standards at each of four grade bands: K-2, 3-4, 5-7, and 8-12. Further explaining the benchmarks is a list of "indicators" (much like individual standards) and corresponding instructional examples. Teacher notes (which offer further clarification to the standards) are also provided for each benchmark. A single-page overview table presents a handy panoramic view of the whole.

The choice of an 8-12 grade span leads to ambiguity, especially for life science. What part of this material is intended for middle school life science and what part for a high school biology course? The chemistry and physics sections are clearly labeled and presumably intended for the traditional high school courses, though there is a parallel ambiguity inherent in their classification under the 8-12 grade band, which would typically embrace a lower-level physical science course as well.

Content and Rigor

The Kansas science standards are better than average in most areas. Essential content is present, and the document generally does a satisfactory-to-admirable job of building in complexity through the advancing grade levels. But a few serious gaps exist, and the treatment of earth and space science is disappointing.

Document(s) Reviewed

- *Kansas Science Education Standards*. August 2007. Accessed from: http://www.ksde.org/LinkClick.aspx?fileticket=YgH0PnTTzS4%3d&tabid=144&mid=8019&forcedownload=true

The silly glossary does the document no favors. Here are a few of the most simplistic and banal examples:

> **Investigation – finding the answer to a question.**
>
> **Properties – a word that describes an object based on direct observations using touch, sight, hearing, taste, smell, and measurement.**
>
> **Structures – parts of the organism that serve different functions in growth, survival, and reproduction.**

Scientific Inquiry and Methodology

Given Kansas's past flirtations with creationism and attempts to broaden the definition of science to include non-naturalistic explanations, these standards are refreshingly clear, direct, and useful. Up front, they state that "science is restricted to explaining only the natural world using only natural cause." Process and its allied areas are covered in four of the standards: science as inquiry, science and technology, science in personal and environmental perspectives, and history and nature of science. Apart from some vacuity ("people practice science"), the inquiry standards are excellent. History of science receives good attention, with explicit recommendations to tie laboratory work to historical investigations. Helpfully, when considering science in society, one goal is to have students realize that "there are many issues which...go beyond what science can explain, but for which solid scientific literacy is useful."

Physical Science

The physical science coverage begins in a conventional manner in Kindergarten through second grade, with such items as these:

> **The student…**
>
> **1. observes *properties of objects* and measures or describes those *properties* using age-appropriate tools and materials.**
>
> **2. separates or sorts a group of objects or materials by *properties*.**
>
> **3. compares the properties of solids and liquids.**
>
> **4. describes the position of an object in relation to other objects. (grades K-2; original emphases)**

This conventionality is not surprising, since the Kansas standards are explicitly modeled after the *National Science Education Standards* (NRC, 1996), which are introduced similarly.

These concepts are revisited at the higher grade spans, with increasing depth and detail. Sound, magnetism, and electricity are introduced in third and fourth grades. Plasmas (gas-like states of matter containing electrons and positive ions but overall neutral) are added to the states of matter that students are to understand in grades five through seven, which is a bit puzzling, since the electron is not introduced until much later, in high school chemistry. Numerous other topics are also introduced in this grade span. Missing, however, are such important topics as kinematics (velocity and acceleration are not defined before high school physics) and a decent definition of kinetic and potential energy or of gravity. There is no coverage of light at all. Given these lacunae, and the frequent shallowness of presentation for the subjects that are covered, the overall quality of preparation for student success at the high school level is not what it ought to be.

High School Physics

The development of kinematics and dynamics in the standards covering grades eight through twelve is perfectly logical, complete though compact, and placed where it belongs, at the beginning of the physics section. It could serve as a model for other states:

> **a. The kinematic (motion) variables: position, velocity, and acceleration can most concisely be described as vectors.**
>
> **b. Velocity describes how position changes and acceleration describes how velocity changes.**
>
> **c. From the definitions of velocity and acceleration, one can derive equations that relate the kinematic variables.**
>
> **d. Acceleration occurs when there is either a change in speed or a change in direction. In the case of uniform circular motion, the acceleration points towards the center of the circle. The magnitude of this acceleration is constant, and is related to the speed of the object and the radius of the circle.**
>
> **e. In the absence of a net force, an object's velocity will not change.**
>
> **f. In the presence of a net force, an object will experience an acceleration which is modeled mathematically by Newton's second law.**
>
> **f. [*sic*] The force that one object exerts on a second object has the same magnitude but opposite direction as the force that the second object exerts on the first. (grades 8-12)**

The treatment of energy is not quite so elegant. But at least there is a systematic attempt to make a formal statement of the first and second laws of thermodynamics. The statement of the first law is correct: "The total internal energy of a substance (the sum of all the kinetic and potential energies of its constituent molecules) will change only if heat is exchanged with the environment or work is done on or by the substance. In any physical interaction, the total energy in the universe is conserved." While the last statement is not really part of the law, the statement is precise and correct. But, as is so often the case, the second law is bungled. It says: "The second law of thermodynamics...states the entropy of the universe is increasing." But that is a *consequence* of the second law, whose two logically equivalent statements are the Clausius statement, "No process is possible in which the *only* event is the transfer of heat from a cooler body to a warmer one," and the Kelvin-Planck statement, "No process is possible in which the only event is the conversion of heat into work." Note that neither of these statements mentions entropy, that magic word that everyone uses but few understand. It seems to be *de rigeur* for science standards to bandy it nonetheless.

The zeroth law is correctly stated but not labeled as such.

High School Chemistry

The chemistry materials are too thin and skip too many important topics. Among the most important absentees are the full definitions of pH, moles, solution concentration units like molarity and percentages, electronegativity (which leads to polar bonds), Lewis dot structures, the gas law relations, and chemical equilibrium. Redox reactions are mentioned, if too briefly. On the positive side, acid-base chemistry is well covered, even including such refinements as pH and pOH, hydronium ion and hydroxyl ion concentrations, titration, and reaction products. There is also laudable coverage of intermolecular attractions and properties of ionic and molecular (covalent) solids.

Earth and Space Science

The Kansas standards for earth and space science are particularly problematic. Some important material is covered, but it is only very rarely developed. Topics are simply mentioned or glossed over, giving little confidence that students will learn the critical content they need. Take, for example, the following standard for grades eight through twelve:

> **The rock cycle describes constructive and destructive processes that change the forms of rocks and soil (solid earth). (grades 8-12)**

This mentions the rock cycle but says nothing about the processes and conditions involved except that they are somehow constructive or destructive, and nothing about cycling of materials into different classes of rocks.

In addition, the state provides a list of vocabulary words that students should learn to prepare for the eighth-grade state assessment, and while many of the terms that appear in that list cover critical content—like convergent or divergent plate boundary and atmospheric layers—those topics are either never mentioned or are not well explained elsewhere in the document.

Unfortunately, some material that is entirely suitable for treatment in Kindergarten through seventh grade is inexplicably deferred until grades eight through twelve. A few examples are galaxies, atmospheric pressure, the thermal causes of climate and weather, and the rock cycle. Even at that level, the treatment often is thin and vague (although there is a good exposition of uniformitarianism).

Life Science

The Kansas standards include most of the essential life science content, including some excellent material on neurons, which is uncommon in state standards. In addition, they present an admirable unit on evolution in grades 8-12, making clear that evolution is "a key theoretical framework for the life sciences" and that the indicators in this unit should be "part of any life sciences course curriculum, including biology, botany, zoology, and microbiology."

Unfortunately, a few notable problems and omissions exist. Mendelian inheritance makes an appearance, but with no mention of phenotype, genotype, genes, or DNA. There is only vague mention of hereditary units, and the standards never cover respiration.

In contrast to the fine treatment in eighth through twelfth grades, the treatment of biological evolution in Kindergarten through seventh grade is ambivalent and some critical material seems pushed to the periphery. In standards for fifth through seventh grades, a "Diversity and Adaptations of Organisms" unit describes how diversity derives from adaptation and that failure to adapt leads to extinction. But there is no discussion of evolution, natural selection, or common-ancestry terminology. Students explore how the shape of beaks can influence what food birds can eat, but there is no mention of Darwin's finches, a classical pillar of evidence undergirding Darwin's arguments that has been dramatically demonstrated in a dynamic fashion by the modern work of the Grants.

The teacher notes do prompt teachers to use "examples such as Darwin's finches [to] help develop understanding of natural selection over time." So one must suppose that only the pap in the boxed standards part will be used in evaluations, although a teacher might enrich the classroom experience with the genuine concepts found in the teacher notes. The implication is that biological evolution is not part of K-7 standards, but only peripheral to them as a sort of enrichment topic.

Taken together, the Kansas science standards earn a not disreputable five out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.) Given that most of the flaws in the various disciplines involve marginal problems, an overhaul of the earth and space science section would go a long way toward raising the mark.

Clarity and Specificity

Despite some confusion that derives from the occasional scrambled and illogical presentation of content, the standards are generally clear, well-presented, and as specific as they can be in a grade-span, rather than grade-by-grade, format.

Associated with every indicator and its examples are teacher notes, some of which are both clear and scientifically solid. For example, the following teacher notes are presented for third and fourth grades:

> **The concept of sound is very abstract. To make the connection between vibrations and sounds more concrete, have students listen to, touch, and watch the object (tuning fork, audio speaker, ruler on the edge of the table, etc.) being used to produce the sound/vibration. Then attempt to connect the controlled experimental sounds with other observed sounds such as jets rattling windows, intercom speakers, class bells, and [with the concept that] all sounds are ultimately the result of vibrations. (grades 3-4)**

The Kansas science standards often hit the target (sometimes with bull's-eyes) but there are misses as well; thus they earn an average score of two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Kentucky

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	2/7	3/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**2.0**
Scientific Inquiry & Methodology	2
Physical Science	4
Physics	0
Chemistry	0
Earth & Space Science	3
Life Science	3
Clarity & Specificity	**1.1**

Average numerical evaluations

Overview

The Kentucky science standards are lamentable less for their flaws—though they are plenty—than for their failed potential. A scaffold exists for what might have been an effective set of standards. But the documents are so short on details—including some critical content—that the standards fail to provide the backbone for a rigorous K-12 science curriculum.

Organization of the Standards

Kentucky's *Core Academic Standards* document presents grade-specific science standards for grades 4-8 only; grades K-3 (primary elementary) and high school (secondary high school) are presented by grade band. For each grade or grade band, standards are first presented by "big idea," or strand. These big ideas are divided into two categories: "primary enduring knowledge—understandings" (e.g., "most living things need water, food and air, while nonliving things can continue to exist without any requirements") and "primary skills and concepts" (e.g., "describe the basic needs of organisms and explain how these survival needs can be met only in certain environments"). Grade-specific or grade-band standards are then provided for each category.

A second document, titled *Transformations*, is concerned mainly with instructional strategies and adds little or no content to the first one.

Content and Rigor

The Kentucky standards tend to swing between imprecision and silence. In some areas—physics in particular—the content is woefully thin. Even the disciplines that are better stocked are marred by sloppy development, errors, and confusion.

Scientific Inquiry and Methodology

The science process standards are scattered across various "big ideas" within the "primary skills and concepts" category, making it difficult to track what, specifically, students should master at each grade level. Worse still, the single set of process standards presented for Kindergarten through third grade renders it impossible to see how these skills accumulate in an age-appropriate manner over the four-year period—

Document(s) Reviewed

- *Kentucky Core Academic Standards—Science*. 2010. Accessed from: http://www.education.ky.gov/users/otl/POS/POS%20with%20CCS%20for%20public%20review.pdf
- *Kentucky Transformations—Science*. 2006. Accessed from: http://www.education.ky.gov/KDE/Instructional+Resources/Curriculum+Documents+and+Resources/Transformations/

one which is crucial to the development of higher scientific abilities.

Several important topics are vaguely introduced, then not revisited for several grades, if at all. For example, the concept of theory is introduced in seventh grade with only the following "understandings" standard:

> **Investigations are conducted for different reasons, including to explore new phenomena, to check on previous results, to test how well a theory predicts, and to compare different theories. (grade 7)**

There is no further mention until the following "understandings" standard from high school life science:

> **In science the term theory is reserved to describe only those ideas that have been well tested through scientific investigation. Scientific theories are judged by how well they fit with other theories, the range of observations they explain, how well they explain observations, and their usefulness in predicting new findings. Scientific theories usually grow slowly through contributions from many investigators. (high school)**

Similarly, the *only* use of hypothesis appears in high school life science as well, with the following "skills and concepts" standard:

> **Distinguish between a scientific law, theory, hypothesis and unsupported supposition/claim. (high school)**

The standards present a complete lack of consistency across disciplines in high school. As noted above, only within the biological sciences is explicit mention made of concepts such as theory and hypothesis. Some disciplines mention the need for accurate record keeping and openness, others do not. Some ask students to examine current ideas and their social impact, some don't. The document at this level lacks cohesion and suggests numerous authors with differing visions. Surely, there is a skill set that all science students at the high school level should be developing, irrespective of the discipline.

On the plus side, there are explicit standards for reading and writing about the sciences. However, one has to read the English language arts standards to discover them.

History receives scant explicit attention beyond an examination of the history of the theory of plate tectonics in high school earth and space science and that of "a variety of accepted scientific laws, theories, and claims" within the biological sciences. Social implications of scientific and technological developments are examined in high school.

Physical Science/High School Physics/High School Chemistry

The physics part of physical science fares poorly. Indeed, the word "physics" doesn't come up in a global search of the entire document. "Similarities in anatomy and molecular chemistry" is the only occurrence of "chemistry," though "chemical" turns up in many appropriate places.

In the intermediate grades, the only mention of magnetism occurs in this standard:

> **Gather information including temperature, magnetism, hardness and mass using appropriate tools to identify physical properties of matter. (grade 4)**

And the only substantive mention of Newton's laws of motion comes in sixth grade, with this statement:

> **At the middle level, qualitative descriptions of the relationship between forces and motion will provide the foundation for quantitative applications of Newton's Laws. (grade 6)**

A clarifying statement adds: "When any force acts on an object, the change in speed or direction depends on the size and direction of the force," which is the truth—but not the whole truth.

These statements are more or less repeated in seventh and eighth grades, with nothing substantive added. In spite of the promise made that these ideas will be "fully developed at the high school level along with the use of models to support evidence of motion in abstract or invisible phenomena such as electromagnetism," the only further mention of Newton's laws at the high school level is this directive: "Investigate Newton's Laws of Motion and Gravitation. Experimentally test inertia and gravitational acceleration."

The chemistry standards are equally weak. In material for sixth grade, for example, we read that "inside a closed system, the temperature increases or decreases as heat energy is added or removed." Of course, this is false if the sample is undergoing a phase change.

At the high school level, we learn that the rate of a chemical reaction is "influenced by a number of variables." That statement is followed by a standard that asks students to "identify and test variables that affect reaction rates" and to "predict the effects of changes in variables (concentration, temperature, properties of reactants, surface area and catalysts)." Unfortunately, these three statements do not appear to be connected at all.

At the high school level, the lack of separate standards for physics and chemistry is particularly disappointing. Nothing in the entire document is relevant to a course in high school physics or chemistry.

Earth and Space Science

Like Kentucky's standards in other science disciplines, the standards for earth and space science are severely flawed. Important content is entirely missing, especially concerning rocks and minerals, the mechanics of earthquakes and volcanoes, and the details of plate tectonics.

There are but occasional glimmers of substantive content. For example, in eighth grade, we are told that students will understand the following:

> **The Earth is almost unimaginably old when viewed on a human time scale, and some processes that shape it are happening so slowly they cannot be easily detected in a lifetime. The accepted age of our Earth and solar system (4.6 billion years) is based on a wide variety of data collected by a number of different methods.**
>
> **Heat flow and movement of molten rock within the interior of the Earth results in crustal changes such as earthquakes, volcanoes, and continental drift.**
>
> **A model cannot represent a full-scale phenomenon with complete accuracy, even if it only addresses very few attributes of the original. (grade 8)**

Life Science

The earlier grades provide poor preparation for high school work, but there is some good material at the high school level, particularly with respect to heredity. However, there is *no* physiology; the eighth-grade material on the nervous system is the last thing students will learn about how their bodies work. Searches for "digestion" and "lung," for example, yield nothing.

In addition, some of the vagueness that permeates the lower grades does persist into high school. For example, one standard directs students to "describe and classify a variety of chemical reactions required for cell functions," and another to "explore the composition and function of the carbon compounds involved in metabolism." Neither of these includes any substantive content.

The standards also describe photosynthesis as a metabolic process, which it is not. And such key words as chloroplast and mitochondrion never appear.

The treatment of evolution deserves special mention. One of the "big ideas" is "biological change." Under this rubric, there is a good treatment of fossils in second grade, with a somewhat repetitious mention in fourth grade. Seventh grade offers this tantalizing "understandings" standard: "Fossils provide evidence of how biological change over time accounts for the diversity of species." This is followed in eighth grade by the equally promising "understanding" standard, "Observations of the fossil record provide evidence that helps to explain why externally diverse organisms are so similar at the molecular level," paired with the "concepts and skills" standard, "Research the most common fossils used to support theories of biological change."

But up to this point, the word *evolution* does not appear once. It finally appears, shyly, in the statement of the "big idea" of "biological change" at the high school level:

> **The only thing certain is that everything changes. At the high school level, students evaluate the role natural selection plays in the diversity of species. Modern ideas of evolution provide a scientific explanation for three main sets of observable facts about life on Earth: the enormous number of different life forms we see about us, the systematic similarities in anatomy and molecular chemistry we see within that diversity, and the sequence of changes in fossils found in successive layers of rock that have been formed over more than a billion years. (high school)**

This paragraph is followed by a clear statement of such important elements of evolutionary knowledge as natural selection, fossils, DNA sequences, anatomical similarities, and embryology. Yet the word "evolution" is never seen again.

These gaping content holes bring Kentucky's average score down to a two out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

Lack of specificity and general ambiguity is a persistent problem for the Kentucky standards. And sometimes we find one without the other—an equally discomfiting situation. Long passages of vague statements are sometimes punctuated by excessively detailed bits that students cannot possibly address.

For example, in sixth grade, after general statements about responding to external environment, we suddenly face the following standard:

> **Explain how various organisms sense (e.g., hunger, fatigue, temperature awareness) and control their internal environments (e.g., fat metabolism, adrenaline release, perspiration) and how this contributes to their survival. (grade 6)**

At this point students have seen nothing about fat or metabolism or hormones or neural function, so what they would do with it is a mystery. Too many ideas are alluded to, glanced at, approached obliquely, or mentioned vaguely in comma-delineated lists such as the above—or students are simply asked to look them up.

Much time and effort must have gone into the preparation of this 563-page document, but the approximately seventy-five pages devoted to science do not constitute a useful tool for guiding those whose task it is to realize a system of science education. Consequently, Kentucky earns an average score of one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Louisiana

GRADE	SCORES		TOTAL SCORE
B	Content and Rigor	5/7	7/10
	Clarity and Specificity	2/3	

REPORT CARD

Content & Rigor	**4.7**
Scientific Inquiry & Methodology	2
Physical Science	5
Physics	4
Chemistry	6
Earth & Space Science	5
Life Science	6
Clarity & Specificity	**2.2**

Average numerical evaluations

Overview

The Louisiana science standards are reasonably challenging and comprehensive, but they suffer from a devastating flaw: Thanks to the state's 2008 Science Education Act, which promotes creationism instead of science, the standards (especially for biology and life science) are haunted by anti-science influences that threaten biology education in the state.

Organization of the Standards

Louisiana's K-8 science standards are divided first into four strands: science as inquiry, physical science, life science, and earth and space science. Each strand is then divided into a series of sub-strands and finally into grade-level expectations.

The high school standards are organized similarly, except that they are presented by course rather than by grade for each of the following: physical science, biology, chemistry, physics, earth science, and environmental science.

Building upon Louisiana's grade-level expectations are the state's comprehensive curriculum documents, available for each of the aforementioned grades and courses.

In addition to the state standards and optional curriculum resources, Louisiana's 2008 Science Education Act encourages cities, parishes, or local school boards to supplement state standards and curricula with materials that promote "critical thinking skills, logical analysis, and open and objective discussion of scientific theories including, but not limited to, evolution, the origins of life, global warming, and human cloning." The statute is a far-from-subtle encouragement to teach creationism instead of science, and to introduce nonexistent "scientific controversies" into the classroom under the false cloak of the genuine uncertainties that always exist at the frontiers of science and are the grist for scientific progress. It directs teachers to "teach the material presented in the standard textbook supplied by the school system" and to "use supplemental textbooks and other instructional materials to help students understand, analyze, critique, and review scientific theories in an objective manner…" While this act does not directly impact the Pelican State standards themselves, the impact of this Act is to undermine the teaching of critical scientific content.

Document(s) Reviewed

- *Louisiana Grade Level Expectations: Science*. 2004. Accessed from: http://www.doe.state.la.us/topics/gle.html
- *Louisiana Comprehensive Curriculum: Science*. 2008. Accessed from: http://www.louisianaschools.net/topics/comprehensive_curriculum.html

Content and Rigor

While the Louisiana standards are reasonably comprehensive, the rigor varies greatly across and within content areas and from grade to grade, making it difficult to believe that all students will be exposed to a sufficiently (or equally) rigorous and thorough K-12 science curriculum.

Scientific Inquiry and Methodology

At every grade level, "science as inquiry" is divided into two strands: "the abilities necessary to do scientific inquiry" and "understanding scientific inquiry." Both present cumulative lists of expectations but fail to articulate how these are related to the content areas. We are instead presented with a sterile list of "abilities." There are global statements such as "explain and give examples of how scientific discoveries have affected society." But, with nothing to guide the teacher as to grade-appropriate examples, these seem empty. Sadly, such nebulous standards are the rule, rather than the exception, in this domain.

Equally troubling, another global statement asks students to "explain how skepticism about accepted scientific explanations (i.e., hypotheses and theories) leads to new understanding." This cracks the door open to an invasion by creationists, particularly in light of the state's Science Education Act (discussed above).

The history of science—a useful pedagogical tool for the teaching of scientific process—receives no mention at all.

Physical Science

The physical science standards for Kindergarten through eighth grade are troubling for a number of reasons. For starters, too many grade-level expectations are repeated nearly verbatim across grade levels, making a progression or accumulation of content and rigor difficult to discern.

In addition, the rigor of the standards is inconsistent. The fourth-grade physical science standards, for example, are clear and appropriately rigorous. Many standards, however, are inappropriate for the grade. For instance, pre-Kindergartners and Kindergartners are to "express data in a variety of ways by constructing illustrations, graphs, charts, tables, concept maps, and oral and written explanations as appropriate," and to "express ideas about demonstrations or experiments (e.g., drawings, journals, reports, presentations, exhibitions, portfolios)." A tall order for such young students.

Finally, some important content is omitted entirely. For instance, a ninth-grade physical science course, which (as is typical) includes standards for both chemistry and physics, leaves out a substantial amount of critical content, including such key subjects as the laws of thermodynamics, the mole concept, the ideal gas law, kinetic theory, atomic structure, metallic and hydrogen bonding, and chemical equilibrium.

High School Physics

In the high school physics course (recommended for grades 11-12), the section titled "forces and motion" is a hodgepodge. It's no accident that high school physics content is presented in pretty much the same order in nearly all textbooks, but that strong hint has been ignored by Louisiana's standards writers. Their items cover the essential content, including such important topics as kinematics and curvilinear and oscillatory motion, with reference to gravitational, electrostatic, and strong nuclear forces. But the order of the items present is hopelessly scrambled, and neither Newton's laws nor analysis of one-dimensional motion appears.

High School Chemistry

Louisiana's standards offer an ambitious scope of study, dealing with most chemistry content well: oxidation reactions, carbon chemistry, and stoichiometry are all thoroughly covered. Some examples:

> **Predict the kind of bond that will form between two elements based on electronic structure and electronegativity of the elements (e.g., ionic, polar, nonpolar). (high school chemistry)**
>
> **Calculate pH of acids, bases, and salt solutions based on the concentration of hydronium and hydroxide ions. (high school chemistry)**
>
> **Compute percent composition, empirical formulas, and molecular formulas of selected compounds in chemical reactions. (high school chemistry)**

Though minor, the most significant shortcoming of the Louisiana chemistry standards is that some critical prerequisite content is missing. For example, high school chemistry students are asked to:

> **Predict the direction of a shift in equilibrium in a system as a result of stress by using LeChatalier's [*sic*] principle. (high school chemistry)**

Unfortunately, students have not yet been asked to understand reaction rates. This knowledge is essential for comprehending equilibrium, equilibrium constants, and equilibrium expressions. Students need to understand thoroughly the concept of equilibrium in order to comprehend stresses to the system.

Another expectation asks students to "draw accurate valence electron configurations and Lewis dot structures for selected molecules, ionic and covalent compounds, and chemical equations" (high school chemistry). There are two problems with this standard: Lewis dot structures are not used for chemical equations, and valence electron configurations are used only for atoms or their ions—not for molecules, compounds, or chemical equations.

By addressing these concerns and adding material on kinetic molecular theory, the ideal gas law equation, and molecular shapes, the Louisiana chemistry standards could get closer to perfect.

Earth and Space Science

The Louisiana earth and space science standards contain a good deal of key content, some of it with impressive depth and rigor, particularly in Kindergarten through eighth grade. For instance, the subject of plate tectonics is well covered, as are the rock and water cycles, mineral properties, and the solar system. The eighth-grade standards even include a strong reference to the Hertzsprung-Russell diagram.

Unfortunately, the high school standards are insufficiently rigorous and are missing some important material. Astronomical units are not mentioned. Neither are the mechanics and measurement of earthquakes, volcanism, the greenhouse effect, or the solar cycle. Climate and weather are poorly developed.

The quality of the activities provided in the optional *Comprehensive Curriculum* is mixed. Even when a topic is well covered by the standards, the suggested curriculum sometimes fails to develop the topic sufficiently. For instance, an activity on Bowen's reaction series provides little explanation for the observed phenomena. In addition, the curriculum often includes silly activities, such as pressing modeling clay, supposedly to mimic metamorphism and give some sort of information about foliated versus monomineralllic textures. It doesn't.

Life Science

The life science standards for Kindergarten through eighth grade are generally quite strong and include much important information, some of it covered with impressive depth. For example, in fourth grade, students are asked to "explain the primary role of carbohydrates, fats, and proteins in the body." Many states don't even include this content in high school, but here, the state not only expects students to know it, but also provides supplemental material that helps define these terms in grade-appropriate ways.

The seventh-grade biology standards are also excellent, as are the high school standards, and both cover nearly all of the essential content well.

The most significant drawback to the standards covering Kindergarten through eighth grade is the omission of evolution. Indeed, the term evolution doesn't appear at all. Instead, eighth graders are asked only to:

> **Compare fossils from different geologic eras and areas of Earth to show that life changes over time. (grade 8)**

Asking students to understand that life changes over time is not the same thing as asking them to learn the building blocks of evolutionary theory.

Fortunately, the high school coverage of evolution is reasonably strong. Tenth graders, for example, are asked to:

> **Analyze evidence on biological evolution, utilizing descriptions of existing investigations, computer models, and fossil records. (high school biology)**

In addition, the comprehensive curriculum provides useful and rigorous supplemental material that further clarifies what the state expects students to know about evolution.

Taken together, these strengths and drawbacks earn Louisiana a solid average score of five out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

In general, the Louisiana standards are clearly written, using verbs we all understand. The state appropriately asks students to "use scientific notation," "write and name formulas," and "calculate."

At times, however, the standards are poorly organized, and there are several standards that are too vague to inform curriculum and instruction. In high school physical science, for example, students are expected to "measure and calculate the relationships among energy, work, and power." Such an exercise would be useful indeed—but without a bit of guidance it's destined to fail.

The writing at times is equally ambiguous, with equally unfortunate implications. In high school, for example, students are asked to "draw accurate valence electron configurations and Lewis dot structures for selected molecules, ionic and covalent compounds, and chemical equations." That's a bit sloppy. One can draw an electron configuration for an atom or ion. Lewis dot structures can be made for atoms and their ions, but they are used primarily for covalently bonded molecules and polyatomic ions. But chemical equations?

Still, flaws like these appear so infrequently that the general impression of the curriculum is positive, as is reflected in the score of two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Maine

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	3/7	4/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**2.5**
Scientific Inquiry & Methodology	5
Physical Science	3
Physics	0
Chemistry	0
Earth & Space Science	3
Life Science	4
Clarity & Specificity	**1.0**

Average numerical evaluations

Overview

Maine's science and technology standards, and their performance indicators, are admirably concise—even terse. Unfortunately, the documentation shows how succinctness can easily devolve into shallowness. After reading these standards, it's virtually impossible to discern what critical scientific content Maine students must learn before they graduate.

Organization of the Standards

Maine's science standards are first divided into five "standards" (commonly thought of as strands): unifying themes, the skills and traits of scientific inquiry and technological design, the scientific and technological enterprise, the physical setting, and the living environment. Each strand is then broken down into a series of sub-strands, for which the state provides performance indicators (or standards) for four grade bands: preK-2, 3-5, 6-8, and 9-Diploma.

In addition, Maine supplies "descriptors" meant to clarify the content that students should master to demonstrate proficiency on each indicator. For example, an indicator for grades 3-5 asks students to "explain interactions between parts that make up whole man-made and natural things." The two attached descriptors direct students to:

> **Give examples that show how individual parts of organisms, ecosystems, or man-made structures can influence one another.**
>
> **Explain ways that things including organisms, ecosystems, or man-made structures may not work as well (or at all) if a part is missing, broken, worn out, mismatched, or misconnected. (grades 3-5)**

No course-specific expectations are presented for high school biology, physics, or chemistry.

Content and Rigor

Maine's motto is "I Lead," but apparently not by example. These standards simply do not provide enough instances of concrete content upon which to base a curriculum. Great swaths are missing, including basically all of physics and chemistry. What does appear, however, tends to be adequately rigorous, grade-appropriate, and well

Document(s) Reviewed

- *Maine Learning Results: Parameters for Essential Instruction.* 2007. Accessed from: http://www.maine.gov/education/lres/scitech/natlstandards.html stated—which only serves to highlight the many voids in the standards.

Scientific Inquiry and Methodology

Nearly two-thirds of the Maine standards are devoted to the process of science in its broadest sense—only about 40 percent of the material deals with traditional content. Not only does this inappropriately prioritize science *process* over content, but the process standards themselves are often inadequate. For instance, students in middle school are expected to "use mathematics to gather, organize, and present data" (grades 6-8) while in later grades they "use statistics to summarize, describe, analyze, and interpret results" (grades 9-Diploma). How these goals differ, or how the rigor is meant to increase through the grades, is impossible to know.

In middle school, students are expected to "communicate, critique, and analyze their own scientific work and the work of other students" (grades 6-8) but not to defend their ideas from such critiques. (A goal for ninth grade and beyond is to "describe how scientists defend their evidence and explanations using logical arguments and verifiable results.") Surely, if students are expected to critique the claims of others, they must be able to defend their own!

The section on "history and nature of science" contains a few statements that give reason for pause and asks students to wade into the murky depths of the problem of demarcation between science and pseudoscience. This is a subject in itself, and it requires more background than these standards present or than schoolchildren can reasonably be expected to possess.

Physical Science/High School Physics/High School Chemistry

While these standards are not significantly marred by errors or confusions, that is largely because there is very little *content* in them. For example, in the grade band covering third through fifth grades, students are asked to "illustrate how many different substances can be made from a small number of basic ingredients." What content is meant to be learned is a mystery.

There are a few flashes of competence. Take, for example, the following standards:

> **Use examples of energy transformations from one form to another to explain that energy cannot be created or destroyed. (grades 6-8)**

> **Explain the relationship between kinetic and potential energy and apply the knowledge to solve problems. (grades 9-Diploma)**

Unfortunately, these are the exception rather than the rule and, as a result, far too much content is glossed over or omitted entirely.

Earth and Space Science

As noted above, the earth and space sciences are lumped together with the physical sciences and, accordingly, this important content domain gets short shrift. For example, a characteristically poor standard requires students to "describe and analyze the effects of biological and geophysical influences on the origin and changing nature of Earth Systems" (grades 9-Diploma). Again, exactly what is expected of the student?

Contrasting with this overwhelming generality are some cogent, specific entries that detail important content students should learn. Take, for example, the following:

> **Explain how the tilt of Earth's rotational axis relative to the plane of its yearly orbit around the sun affects the day length and sunlight intensity to cause seasons. (grades 6-8)**

Or:

> **Describe Earth's internal energy sources and their role in plate tectonics. (grades 9-Diploma)**

But there is not enough of such specific material to overcome the vague generalities of the whole.

Life Science

Maine's standards make a laudable early effort to include evolution. The concept of biological adaptation appears in third and fourth grades. Fossils are studied in fifth through eighth grades, and evolutionary biology appears in high school. But simplification and compression result in language that is potentially misleading or simply incomprehensible.

The same unfortunate constriction mars the "living environment" strand. The coverage is either too generalized or so compressed as to imply what is not necessarily true. For example, in high school students are asked to "describe the interactions that lead to cell growth and division (mitosis) and allow new cells to carry the same information as the original cell (meiosis)" (grades 9-Diploma). But it is not necessarily the case that in meiosis all new cells "carry the same information as the original cell." Indeed, the reverse can be true, with important consequences.

With so many instances of such frustrations, and given the absence of any treatment of high school chemistry or physics, Maine's mean content score is a disappointing three out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Maine standards lack both clarity and specificity. For starters, what little content exists in them is buried beneath a tangled and confusing web of strands and sub-strands, where important content from different areas of science—life science, earth and space science, physical science, and so on—are mingled, making it difficult for teachers to extract the guidance they need to provide rigorous, content-driven instruction.

Worse, this confusing presentation is grounded on the faulty premise that organizing standards by *theme*, rather than by content, will better "provide teachers and students with a scaffold on which to organize the details of the standards." Of course, it's difficult to equate *theme* with *knowledge*, except in some loose way. And alluding to genuine knowledge vaguely or sketchily under some theme does not serve as a standard for teaching or learning.

Equally frustrating are the places where the standards are written so ambiguously that they provide virtually no indication of what, precisely, students should know and be able to do. In the physical science material, for example, the "matter and energy" section asks students to:

> **Describe how the number and arrangement of atoms in a molecule determines a molecule's properties, including the types of bonds it makes with other molecules and its mass, and apply this to predictions about chemical reactions. (grades 9-Diploma)**

It would not be easy to come up with a more succinct summary of the purposes and content of all of modern chemistry. But what is the student really supposed to know? What about chemical bonds? And, in fact, which properties of a molecule are *not* germane to its actual or potential involvement in chemical reactions?

On another page comes this remarkable compression: "Describe the relationship between electric and magnetic fields and forces, and give examples of how this relationship is used in modern technologies" (grades 9-Diploma). Even without the obligatory nod to technology, a minimally cogent response would require a brilliant student to write a long and erudite essay *or* present a lengthy seminar.

In these instances, the close shave is as bad as a deep cut. The average score for clarity and specificity, a one out of three, reflects this disconnect. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Maryland

GRADE	SCORES		TOTAL SCORE
B	Content and Rigor	5/7	7/10
	Clarity and Specificity	2/3	

REPORT CARD

Content & Rigor	**5.0**
Scientific Inquiry & Methodology	5
Physical Science	6
Physics	3
Chemistry	5
Earth & Space Science	6
Life Science	5
Clarity & Specificity	**1.6**

Average numerical evaluations

Document(s) Reviewed

- *Maryland Standards: State Curriculum.* 2008. Accessed from: http://mdk12.org/instruction/curriculum/science/index.html
- *Maryland Core Learning Goals: Science.* 2003. Accessed from: http://mdk12.org/instruction/curriculum/science/clg_toolkit.html

Overview

The Maryland science standards for grades preK-8 are generally clear and rigorous. The high school standards are weaker, alarmingly so in certain areas. However, the combination gives reason for confidence that students in the Old Line State will graduate having learned the essential science content they need to be college- and career-ready.

Organization of the Standards

Maryland's preK-8 science standards are divided by grade and then into six common strands: skills and processes, earth/space, life, chemistry, physics, and environmental science. Under each strand is a series of topics and, for each topic, one or more "indicators" are provided. Grade-specific objectives (or standards) are then provided for each indicator. Finally, the state has linked publicly released assessment questions to a number of the objectives at each grade level.

At the high school level, "core learning goals" are provided for four courses instead of by grade: physics, earth/space science, chemistry, and environmental science. The standards for these courses are organized similarly to the preK-8 standards, with two exceptions. First, there are only two strands per course—a skills and process strand, and the designated content. Second, because these courses are not assessed by the state, no assessment questions are provided.

In addition to the core learning goals, Maryland provides draft curriculum standards for high school biology that focus on two strands: skills and processes, and life sciences. (These standards have not been formally adopted as of November 2011, but are already widely used by school districts across the state.) Each strand is divided into expectations, for which one or more "indicators" are provided. In addition, the state defines "assessment limits" (topics to be assessed) and objectives for each biology indicator.

Content and Rigor

The elementary and middle school materials furnish a fine basis for curriculum development, generally covering the appropriate content and building on it with increasing complexity through the grades. (In fact, they occasionally expect too much, even for stern critics.) The same cannot be said for high school, however. Although not terminally weak, the content in the upper grades often falls short of the mark, typically by glossing over or omitting critical content.

Scientific Inquiry and Methodology

For each grade or course, the Maryland standards for scientific inquiry and methodology are outlined under a series of four to seven topics in the "skills and processes" strand. While these process standards are generally clear, they suffer from two significant shortcomings. First, they are repetitive, often closely duplicating standards across grade levels and making it nearly impossible to tell what progress is expected of students from grade to grade. Second, beyond the now-popular piety that science has been done by "different kinds of people, in different cultures, at different times," there is virtually no coverage of the historical development of scientific ideas.

Physical Science

The physical science material covers virtually all of the essential content. Thermometers are introduced in Kindergarten, and uniform, accelerated, and periodic motion in fifth grade. Forms of energy are introduced in a clear way in eighth grade. At the same time, work is properly defined in eighth grade, as demonstrated by the following:

> **Identify the relationship between the amount of energy transferred (work) to the product of the applied force and the distance moved in the direction of that force. (grade 8)**

In first grade, we read: "Make a list of possible advantages and disadvantages of differences of individuals in a population of organisms." This exercise provides a good preparation for later inquiry in depth. And it is a delight to read that Maryland asks Kindergartners to "explain that there must be a cause for changes in the motion of an object," with the following:

> **Observe and describe the ways in which a variety of objects' motion can be changed.**
>
> - **Speed up from a stand still**
> - **Slow down to a stop**
> - **Go faster**
> - **Go slower**
> - **No change**
> - **Change direction**
>
> **Based on observations, identify what caused the changes in an object's motion.**
>
> - **Push**
> - **Pull (Kindergarten)**

This explication is clear and entirely comprehensible for children of this age.

Similarly, in appropriately plain terminology for the grade level, we see: the zeroth law of thermodynamics introduced in third grade; "provide evidence that supports the idea that our solar system is sun-centered" in fifth grade; and Kepler's third law in eighth grade.

The good in the document is not unalloyed, however. Excessive repetition from grade to grade is particularly frustrating. For example, the international system of units (SI units) for area, volume, length, and weight in newtons are introduced in third grade and then repeated in fourth and fifth grades. The basic properties of solids, liquids, and gases are also repeated year after year.

At times, the standards ask students to undertake investigations that are impossible to execute. In one example, eighth graders are told to "formulate an explanation for the different characteristics and behaviors of solids, liquids, and gases using an analysis of the data gathered on the motion and arrangement of atoms and molecules." Although we suspect that students will see materials based on this statement in a much simplified form, the wording certainly makes it sound like a task for a university course in chemical thermodynamics.

High School Physics

The high school physics standards are brief but reasonably comprehensive. However, some restrictions are puzzling. Many subjects that lend themselves readily to quantitative discussion are explicitly limited to qualitative or semi-quantitative study. Among these are resolution of vectors (collinear and perpendicular only), projectile motion, and Coulomb's law. This numbers-light presentation runs contrary to the expectations of the traditional high school physics course, in which students are expected to use quantitative methods, including the simple trigonometry required to deal with two-dimensional vectors in any orientation.

In the treatment of thermodynamics, the term "irreversibility" is misused. And in spite of explicit emphasis on practical applications, heat engines are ignored. Finally, the order in which waves are discussed is illogical.

High School Chemistry

Much essential material is missing from chemistry, including equilibrium, gas laws and kinetic theory, quantitative stoichiometry, Lewis dot structures, and structural formulas and nomenclature for organic compounds. Molarity, which is defined as the number of moles of solute per liter of solution, is a quantitative measure by definition. Therefore, it is surprising that this fundamental concept should somehow be taught as "conceptual only" and not thoroughly explored. There is also no discussion of the connection between atomic electron transitions and spectral lines.

Of particular concern is the odd way in which each standard is followed by stringent "assessment limits." These seem designed to make sure the mediocre (or poorer) student doesn't get too low a grade. For instance, students are asked to "describe observed changes in pressure, volume, or temperature of a sample in terms of macroscopic changes and the behavior of particles." The assessment limits then indicate that students will only be assessed on their knowledge of:

- **Constant temperature (effect of pressure or volume change to sample of solid, liquid, or gas)**
- **Constant volume (effect of pressure or temperature change to sample of solid, liquid, or gas)**
- **Constant pressure (effect of temperature or volume change to sample of solid, liquid, or gas). (high school chemistry)**

The implication here is that the student is not to be required to use the full power of the ideal gas law, $pV = nRT$, explicit mention of which is somehow avoided in this rather vague group of standards.

Similarly, students are asked to "balance simple equations (not to include redox reactions)" as in:

- **Law of Conservation of Mass (apply to reactions to account for the same number of atoms of each type appearing in both the reactants and products)**
- **Coefficients (define; use to balance symbolic equations; explain meaning in symbolic equations; differentiate between the use and meaning of coefficients and subscripts). (high school chemistry)**

Admittedly, balancing redox reactions could get more difficult than balancing some other chemical equations, but simpler examples ought to be part of the high school chemistry curriculum. Ironically, the emphasis on "differentiat[ing] between the use and meaning of coefficients and subscripts" is negated in the document itself, with an utterly bewildering demand that students "use symbols to represent elements and polyatomic ions (limited to NH4+1,OH-1, NO3-1, NO2-1, ClO3-1,ClO2-1, HCO3-1, CO3-2, SO4-2, SO3-2, PO4-3, PO3-3; including diatomics – H2, O2, N2, Cl2, Br2, I2, F2; given periodic table and ion chart)."

Earth and Space Science

The earth and space science material is ambitious and generally excellent. In elementary school in particular, the content builds nicely through the grades. Observation of weather begins in pre-Kindergarten and is built upon systematically in grades four and six; similarly, the water cycle is introduced in first grade and there are good follow-ups in grades three, five, and eight. The basic properties of minerals and their place in the structure of rocks are well handled in fifth grade.

At the middle school level, the layered structure of Earth is introduced in sixth grade in some detail, though there is some minor confusion between the crust and the lithosphere.

Then in high school, the life cycles of stars receive adequate discussion, as does the important subject of relative and absolute dating. But the origin of the universe is touched upon only as a parenthetical remark, and plate tectonics is handled merely by a vocabulary list that covers a lot of ground with little explanation.

Unfortunately, while the high school earth and space science content is ambitious, it is also condensed to fewer than eight hundred words, meaning that some concepts—such as the solar cycle and the greenhouse effect—are mentioned without any attempt at exposition of the underlying mechanisms.

Although the effect is a concatenation of everything from the entire universe down to the details of solar activity, it does span plenty of ground.

Life Science

Many unrealistically broad and even impossible expectations populate the elementary and middle school standards for life science. Fourth graders are asked to "examine and compare fossils to one another and to living organisms as evidence that some individuals survive and reproduce." After using microscopes to "observe, describe, and compare single celled organisms," fifth graders are to "cite evidence from data gathered that supports the idea that most single celled organisms have needs similar to those of multicellular organisms." Such data are not evident from microscopy.

Evolution is introduced in eighth grade, but with a troubling feature: Five objectives are listed, but only the first two are to be assessed by the state. The remaining three objectives, which include coverage of natural selection, extinction, and evolution explaining species diversity, are purposely excluded from this assessment. In addition, the notion of common ancestry does not appear until high school, and even then no mention occurs of the deeply ancient nature of this ancestry. Human evolution is ignored.

The high school biology course—the only high school course for which a detailed curriculum is provided—provides a comprehensive and thorough list of topics covered, including in-depth biochemistry, cell biology and its relationship to organ systems and physiology, genetics, evolution, and ecology. Considerable attention has been given to such topics as the role of pH in maintaining life processes, enzyme kinetics, and the molecular biology of gene expression. A student mastering the material in this course would be excellently prepared for a college-level course, and indeed might perform well on an Advanced Placement test.

Overall, the Maryland science standards include much of the essential content that students must learn. As a result, they earn a solid five out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Maryland science standards are well organized and easy to follow. Unfortunately, the clarity of the presentation is often hampered by the vagueness of the standards themselves. Too often, standards are written so broadly that they fail to delineate what, precisely, students should know and be able to do. Take, for instance, this example from the "concepts of physics" core learning goals:

> **The student will relate thermodynamics to the balance of energy in a system. (high school physics)**

While grammatically correct, this sentence contains no meaningful information.

Other standards, while clear, lack the specificity they need to ensure that students learn the requisite content. For instance, in earth and space science, greenhouse gases are mentioned but there is no discussion of where they come from or how they affect Earth's climate. The document also contains a distracting density of typos, including the ever-popular "flourine" for fluorine.

As noted earlier, the standards are also repetitive, often closely duplicating standards across grade levels and making it nearly impossible to tell what progress is expected of students from grade to grade.

Taken together, these drawbacks earn Maryland a two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Massachusetts

GRADE	SCORES		TOTAL SCORE
A-	Content and Rigor	6/7	9/10
	Clarity and Specificity	3/3	

REPORT CARD

Content & Rigor	**5.7**
Scientific Inquiry & Methodology	5
Physical Science	5
Physics	4
Chemistry	7
Earth & Space Science	6
Life Science	7
Clarity & Specificity	**2.8**

Average numerical evaluations

Overview

Conveniently and clearly presented in a single document, the Massachusetts science standards are easy to read and easy to use. The language is straightforward, and the science is mostly sound and presented logically. The standards do suffer from a few faults, however: The treatment of major subjects, like high school physics, is sometimes brief. But overall, these standards provide a solid foundation for planning a K-12 science program.

Organization of the Standards

The Massachusetts K-8 science standards are divided into four familiar strands: earth and space science, life science (biology), physical sciences (physics and chemistry), and technology/engineering. Each strand is then divided into sub-strands, which vary from grade band to grade band. Finally, standards are listed for three grade bands rather than by grade: preK-2, 3-5, and 6-8. The state then provides "ideas for developing investigations and learning experiences," which are meant to help guide classroom instruction, for each grade band.

At the high school level, the standards are similarly organized, though here they are presented by content area, rather than by grade band, for the following: earth and space science, biology, chemistry, introductory physics, and technology/engineering.

Content and Rigor

Across disciplines, the quality and depth of the Massachusetts science standards is strong. The materials, particularly for high school students, are clear and comprehensive. The few stumbles are in the nature of minor omissions rather than major gaps or errors.

Scientific Inquiry and Methodology

The scientific inquiry and methodology standards are straightforward and well integrated with disciplinary content throughout the standards, thus making these process standards an organic element of instruction and learning rather than an afterthought or add-on. Mathematical problem-solving is stressed in concert with investigation and experimentation. Further, the need for students to communicate

Document(s) Reviewed

- *Massachusetts Science and Technology/Engineering Curriculum Framework.* October 2006. Accessed from: http://www.doe.mass.edu/frameworks/scitech/1006.pdf effectively about their work in science, both orally and in writing, is emphasized.

Massachusetts does, however, make a few missteps in handling science as inquiry. For instance, the history of science is shortchanged, and the place of science within society—beyond consideration of engineering design—is largely ignored.

Physical Science

Although generally solid, the physical science standards for pre-Kindergarten through eighth grade suffer from omission or short-changing of several important topics. These include gravitation, kinematics, crystalline solids, and heat, as well as electricity and magnetism, optics, and modern physics. There are also some illogical sequences, as in grades three through five, when magnetic energy is presented first, followed by electromagnets, and finally magnets in general. Also in that grade band, a list of “basic forms of energy” fails to include mechanical energy.

High School Physics

The high school physics standards are systematic, logical, and pedagogically sound. Study of physics begins with kinematics and then dynamics (though Newton’s laws are compressed into a single sentence). This treatment is followed by energy and momentum conservation, with clear mention of the work-energy theorem at the outset. Heat, waves, electromagnetism, and electromagnetic radiation then follow. A supplementary discussion explores mathematical tools that the student is expected to master and use.

The main criticism one can level at the physics materials is their brevity. Not counting auxiliary information, the entire coverage fills fewer than three-and-a-half pages. Modern physics—the physics of the twentieth and twenty-first centuries, comprising quantum mechanics and relativity, among other things—is not covered at all. An excellent course could be planned and implemented on the basis of the physics materials—but so could a fairly sketchy and incomplete one, while still meeting their minimal requirements. One is at a loss to infer with accuracy what depth of understanding students will gain from a course based on this information.

High School Chemistry

The high school chemistry standards are handled with a refreshing level of depth and specificity. They are clearly written, address expected content rigorously, and will prepare Massachusetts’s students to excel in college chemistry. Those students not heading to college will have a better appreciation and understanding of how chemistry impacts their lives. In the “solutions, rates of reaction, and equilibrium” sub-strand, for example, the content includes: the solution process; concentration using molarity in dilution and stoichiometry problems; the factors that affect the rate of dissolving; the properties of solutions vs. pure solvents (colligative properties); the factors affecting chemical-reaction rates; and the prediction of equilibrium shifts due to stress factors (Le Châtelier’s principle).

Just a few important subjects are missing: carbon chemistry, molecular polarity and bond angles, and metallic bonding. Equilibrium is mentioned in the sub-strand header listed above but is not further defined. This missing content is partially offset by the expanded coverage in other areas of chemistry (both basic and more advanced). These standards address topics that include buffers, percent composition, empirical/molecular formulas, percent yield, VSEPR theory, the ideal gas law, stoichiometry, solution dilution, and colligative properties.

A safety note: An “inquiry skills” standard (SIS2) encourages neophyte chemistry students to design their own experiments. Doing so could be very dangerous! This activity should not be assigned without knowledgeable adult supervision.

Earth and Space Science

Overall, earth and space science is covered comprehensively. Particular areas of strength are earthquake processes and relative and absolute dating. Only minor weaknesses mar Massachusetts’s strong standards in this realm of science. The evidence trail leading to the theory of plate tectonics is slighted, and some significant high school subject matter is missing, including stellar evolution and volcanic processes.

Life Science

The life science section begins with an easy to follow, lucid, and to-the-point introduction, spelling out how biological concepts will be presented and developed from pre-Kindergarten through twelfth grade. And, though the standards provide less detail than some other states in the early grades, the critical material is covered—and is well developed. Examples of exercises further explain and back up the standards. The coverage of evolution in grades six through eight is both appropriate and good; the term is used without apology or evasiveness. Evidence from fossils and comparative anatomy is adduced.

High school material is clear and concise, yet also comprehensive. An excellent physiology section goes into substantial detail. Treatment of evolution at the high school level is also thorough; as is the case in almost all states, however, human evolution is absent.

Overall, the Massachusetts science standards present much of the essential content that students need to master. The few drawbacks and omissions bring the overall average score for content and rigor to six out of seven. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

In general, Massachusetts's standards are organized in a clear, unambiguous manner. In earth and space science, for example, students are asked to "recognize, interpret, and be able to create models of the earth's common physical features in various mapping representations, including contour maps" (grades 6-8).

And in high school chemistry we find this series of clear, deep, and specific items:

> **Solutions, Rates of Reaction, and Equilibrium**
>
> ***Central Concepts*: Solids, liquids, and gases dissolve to form solutions. Rates of reaction and chemical equilibrium are dynamic processes that are significant in many systems (e.g., biological, ecological, geological).**
>
> **7.1 Describe the process by which solutes dissolve in solvents.**
>
> **7.2 Calculate concentration in terms of molarity. Use molarity to perform solution dilution and solution stoichiometry.**
>
> **7.3 Identify and explain the factors that affect the rate of dissolving (e.g., temperature, concentration, surface area, pressure, mixing).**
>
> **7.4 Compare and contrast qualitatively the properties of solutions and pure solvents (colligative properties such as boiling point and freezing point).**
>
> **7.5 Identify the factors that affect the rate of a chemical reaction (temperature, mixing, concentration, particle size, surface area, catalyst).**
>
> **7.6 Predict the shift in equilibrium when a system is subjected to a stress (Le Châtelier's principle) and identify the factors that can cause a shift in equilibrium (concentration, pressure, volume, temperature). (high school chemistry)**

In places, however, more detail would help. Again in chemistry, students are told that heat is connected to particle motion and to temperature, but temperature is not defined, nor does it appear in the standards glossary. As another example, one standard asks students to "explain how electromagnets can be made, and give examples of how they can be used" with a corresponding exercise having students "make and use an electromagnet" (grades 3-5). There is no further explanation of how or why doing so might be worthwhile.

Still, these slips are minor, and as such, the Massachusetts standards earn a three out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Michigan

GRADE: **C**

SCORES: Content and Rigor **4/7**; Clarity and Specificity **2/3**

TOTAL SCORE: **6/10**

REPORT CARD

Content & Rigor	**3.8**
Scientific Inquiry & Methodology	2
Physical Science	3
Physics	1
Chemistry	7
Earth & Space Science	5
Life Science	5
Clarity & Specificity	**1.8**

Average numerical evaluations

Document(s) Reviewed

- *Science Grade Level Content Expectations (v.1.09)*. 2009. Accessed from: http://www.michigan.gov/documents/mde/Complete_Science_GLCE_12-12-07_218314_7.pdf
- *Michigan Merit Curriculum, Science.* 2009. Accessed from: http://www.michigan.gov/mde/0,1607,7-140-38924_41644_42814---,00.html

Overview

The quality of Michigan's science standards varies greatly. Depending on grade level and subject matter, they range from thorough and rigorous to error-riddled and illogical. Of particular concern is that much content that is prerequisite for high school content is missing entirely from the K-8 standards.

The inconsistency leaves little confidence that students will graduate from high school having mastered the essential science content.

Organization of the Standards

The Michigan science standards are divided first into four "disciplines," or strands: scientific process, physical science, life science, and earth science. Each strand is further subdivided into three or four sub-strands. Then, grade-specific standards are provided for all grades, K-7.

The high school standards are presented for four courses: biology, earth science, chemistry, and physics. The state assumes that these content expectations will be covered in grades 8-11, with districts setting their own twelfth-grade standards. Each course is divided into strands. Biology, for example, splits into the following: organization and development of living systems, interdependence of living systems and the environment, genetics, and evolution and biodiversity. High school expectations are then identified as either "prerequisites" (what students are expected to know upon entering high school), "essential knowledge" (what graduates are expected to know, regardless of what courses they take in high school), "core knowledge" (what graduates who have completed a discipline-specific course are expected to know), and "recommended knowledge" (knowledge that is desirable as preparation for more advanced study in the discipline, but not required for graduation credit). How or where students who do not take a particular course will acquire the "essential knowledge" is unclear.

Content and Rigor

A common wisecrack about Michigan is that if you don't like the weather, wait a few minutes. The state's science standards seem to have embraced such variability as a guiding principle—and not to their advantage. Some disciplines are strong, even excellent (see chemistry), while others are weak, even disastrous (see physics). And even within a given subject, the rigor is inconsistent; the standards for Kindergarten through seventh grade are typically weaker than the high school content.

Scientific Inquiry and Methodology

The Michigan standards for scientific inquiry and methodology are vague to the point of near uselessness. While they include the usual process skills that students are expected to master in most states (e.g., "develop research strategies and skills for information gathering and problem solving" [grades K-7]), they rarely link these abstract goals to the content that students would need to learn to demonstrate mastery. For example, first graders are expected to "make careful and purposeful observations in order to raise questions, investigate, and make meaning of their findings." That's a lofty but empty requirement, grounded in no substantive content. In third grade, students are asked to describe "how people have contributed to science throughout history and across cultures," and by fifth grade, they are to explain "how science and technology have advanced because of the contributions of many people throughout history and across cultures." Surely, the history of science can be used in a more profitable and focused manner to illustrate how science is—and has been—practiced. The problem continues into high school, where, for example, the goal of analyzing "how science and society interact from a historical, political, economic, or social perspective" is presented with no guidance.

Nor is there much consistency or development of content from grade to grade. For example, second-grade teachers are told that experiences in the classroom should "inspire a sense of wonder and enthusiasm," and Kindergarten teachers are asked to exploit their students' "natural curiosity" for a subject that is of "high interest." Yet after fourth grade, no further mention is made of these elevated (if nebulous) goals.

Similarly, no mention is made from Kindergarten through seventh grade of important concepts such as hypothesis, law, or theory. Yet in high school, students are expected to "describe the distinctions between scientific theories, laws, hypotheses, and observations," something that could certainly occur sooner.

Physical Science

The development of physical science is often chaotic and illogical. Standards appear as a mixed bag of loosely related concepts, some of them poorly or incorrectly stated. The order of materials is scattered and the depth fluctuates wildly.

For example, a sub-strand appearing in third, fourth, sixth, and seventh grades asks students to:

> **Develop an understanding that there are many forms of energy (such as heat, light, sound, and electrical) and that energy is transferable by convection, conduction, or radiation. Understand energy can be in motion, called kinetic; or it can be stored, called potential. Develop an understanding that as temperature increases, more energy is added to a system. Understand nuclear reactions in the sun produce light and heat for the Earth. (grades 3, 4, 6, and 7)**

Here, four entirely distinct concepts are jammed together into a single statement.

Another unfortunate fourth-grade standard asks that students:

> **Measure the weight (spring scale) and mass (balances in grams or kilograms) of objects. (grade 4)**

The implication here is that a pan balance, unlike a spring scale, measures mass directly. It does not; it measures mass by comparing the weights of two samples, one of known mass. There are ways of measuring mass directly (e.g., the oscillating system used to measure the mass of astronauts in orbit) but this is not one.

Other standards are simply wrong. For instance:

> **Demonstrate that non-magnetic objects are affected by the strength of the magnet and the distance away from the magnet. (grade 4)**

Nonmagnetic objects are unaffected by magnets.

High School Physics

At the high school level, in antithesis to chemistry (see below), the treatment of physics becomes a confused mess. Too many standards are so broad as to be instructionally meaningless. Take, for example, the following:

> **Distinguish between rotation and revolution and describe and contrast the two speeds of an object like the Earth. (high school physics)**

What speeds? Is the intent to compare angular speeds (which doesn't make much sense here) or the rotational speed of some part of the earth with something else?

Other standards simply fail to introduce critical content adequately, such as:

> **Calculate force, masses, or distance, given any three of these quantities, by applying the Law of Universal Gravitation, given the value of G. (high school physics)**

Given all three quantities, what is to be calculated?

In places, the content information is muddled and misleading. For instance, students are asked to "explain how energy is conserved in common systems," but an example that follows is "mechanical energy in a collision"—a poor choice, as mechanical energy generally is not conserved in collisions.

The physics standards for the most part avoid the use of mathematical expressions at the cost of introducing confusion. Heat, temperature, and efficiency are unfortunately shoehorned into a single and optional standard.

High School Chemistry

In the early years, chemistry fares little better than physical science. From Kindergarten through seventh grade, the standards repeat the same topics over and over, year after year, with only minimal increase in depth or rigor. Their stated goal is to help students get ready to become scientists and deep thinkers, but one wonders how that will happen when they see such banal subjects as "properties of materials" repeated from grade to grade at the expense of more interesting content and more rigorous and grade-appropriate vocabulary.

Fortunately for Michigan pupils, the high school chemistry standards are generally well written and cover the critical content that students must learn as part of a rigorous, college-preparatory chemistry course.

A few topics are incomplete or missing, such as molarity, percentage of solution by mass or volume, and factors affecting solution formation. The ideal gas law is cited in three standards but never made explicit; certainly the simple equation $pV = nRT$ never appears. But overall, the high school standards are exceptional.

Earth and Space Science

The Michigan earth and space science standards start out weakly; much critical content is omitted from Kindergarten through seventh grade. In fact, while the high school standards list a number of "prerequisites" that students should have learned in earlier grades, many of these are either missing in Kindergarten through seventh grade, or not covered at the level of depth required for the high school content. For example, the high school standards require knowledge of stars and galaxies, but there is no mention of either prior to high school. Similarly, the evidence for the theory of plate tectonics is given as prerequisite to the high school standards, but the Kindergarten through seventh-grade standards do not address this interesting content.

Other topics are glossed over or excluded entirely. For instance, there is some mention of the solar system and planetary motion in fifth grade, but the coverage is insufficient at best. There is vague mention of mineral properties in third grade, but the identification by properties is missing (though this is also listed as a prerequisite for high school). Different types of rocks are referenced in sixth grade, but the rock cycle is neglected.

At the high school level, the *Michigan Merit Curriculum* standards are spectacular in breadth and depth, and often beautifully written. The histories of the universe and solar system are well treated, as are relative and absolute dating techniques. Volcanism is also well covered, as shown by the following illustrative example:

> **Explain how the chemical composition of magmas relates to plate tectonics and affects the geometry, structure, and explosivity of volcanoes. (high school earth science)**

There is much more to praise at the high school level, but the lack of coordination throughout the high school material and the weak support for that material in prior grades causes some concern.

Life Science

Much important life science content is either absent altogether or glossed over from Kindergarten through seventh grade. Evolution, for example, is treated inconsistently and incompletely. Survival, adaptation, and populations are all mentioned, but the standards contain nothing about natural selection or deep history (the distant past of the human species). The word evolution is never used. Fossils are mentioned in fifth grade, but only in passing.

In addition, errors frequently creep in. For instance, a seventh-grade standard asks that students:

> **Examine how through cell division, cells can become specialized for specific functions. (grade 7)**

In fact, that specialization occurs via differential gene expression, not cell division.

Happily, the high school standards are far better, containing excellent content that is systematically and explicitly laid out. The evolution unit is thorough and well done, with references in the contexts of ecosystems, genetics, molecular biology, biodiversity, and taxonomy, as well as a section whose primary subject is evolution.

That said, there are some gaps. For instance, while there is thorough coverage at the high school level of the scales of cells and subcellular systems, and of the scale of ecosystems, organ systems and physiology are not well treated.

A few errors also appear in high school. In biology, for example, students are required to:

> **Recognize and describe that both living and nonliving things are composed of compounds, which are themselves made up of elements joined by energy-containing bonds, such as those in ATP. (high school biology)**

In fact, the important bonds in ATP are specific and unusual.

We are puzzled as to how the quality of treatment of several sciences could be so variable. The standards manage an average score of four out of seven for content and rigor, but that average masks a deeply uneven presentation of science. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Michigan standards are occasionally clear and specific, but much material is too garbled, poorly written, or illogically developed to drive a coherent science curriculum. For instance, in seventh grade, a standard explains:

> **Reflection and social implications are the application of the students' new knowledge and affects their decision making and their perception of the effect humans, scientific discovery, and technology have on society and the natural world. (grade 7)**

This statement, in addition to being grammatically untamed, is meaningless.

More troubling are the instances when the standards reveal a frustrating lack of logical flow. Consider this chain in the physics section (though the problem pervades the standards):

> **Gravitation is a universal attractive force that a mass exerts on every other mass. The strength of the gravitational force between two masses is proportional to the masses and inversely proportional to the square of the distance between them. (high school physics)**

But the following instructions to "predict" or "calculate" cannot be accomplished without the quantitative form of Newton's law of gravitation, $F = GMm/r^2$.

> **Explain earth-moon interactions (orbital motion) in terms of forces. (high school physics)**

Any real "explanation" requires quantitative application of the law above, together with Newton's second law of motion, $F = ma$, which is implied but never made explicit in a preceding standard.

> **Predict how the gravitational force between objects changes when the distance between them changes. (high school physics)**

This is, of course, a vague verbal expression of one aspect of the law of gravitation. Logically, it comes prior to the other items, and so it ought to be stated before them. And the problems persist. How a teacher could be expected to make order out of this chaos is unfathomable.

The deeply uneven quality of the Michigan science standards suggests a failure to subject the document to a final, unified edit by persons who combine scientific expertise with an ability to set forth essential knowledge in a cogent, logical, and precise way. It also earns Michigan an average score of two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Minnesota

GRADE	SCORES		TOTAL SCORE
C	Content and Rigor	4/7	5/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**4.3**
Scientific Inquiry & Methodology	5
Physical Science	3
Physics	2
Chemistry	4
Earth & Space Science	6
Life Science	6
Clarity & Specificity	**1.0**

Average numerical evaluations

Overview

The Minnesota science standards are like the frustrating student who does excellent work two days a week but shoddy work on the other three. When the standards are "on," they are cogent and challenging. But too often they are marred by vague, incorrect, or grade-inappropriate material, or are missing key content entirely.

Organization of the Standards

Minnesota's standards are first divided into four strands: nature of science and engineering, physical science, earth and space science, and life science. Each strand is then divided into three or four unique sub-strands, each of which is further divided into two to four standards. For instance, there are two "standards" in the first physical science sub-strand:

> **STRAND 2: PHYSICAL SCIENCE**
>
> ***Substrand 1: Matter***
>
> **Standard 1. Properties and structure of matter.**
>
> **Standard 2. Changes in matter.**

Finally, grade-specific benchmarks are provided for all grades, K-8.

The high school standards are organized similarly, except that only a single set of benchmarks is provided for the 9-12 grade band.

In addition to the standards for grades 9-12, the state provides course-specific standards for high school chemistry and physics. (High school biology is subsumed under the "life science" strand for grades 9-12.)

Content and Rigor

The unevenness of the Minnesota science standards is evident both within and across subject areas. The treatment of life science and earth and space science is excellent, while that of physical science, and physics in particular, is mediocre or worse. Many of the problems stem from a failure to develop grade-appropriate expectations and to build on those expectations over time. As a result, although examples of

Document(s) Reviewed

- *Minnesota Academic Standards in Science K-12*. 2009. Accessed from: http://education.state.mn.us/mdeprod/idcplg?IdcService=GET_FILE&dDocName=005263&RevisionSelectionMethod=latestReleased&Rendition=primary

rigorous content abound, they often seem out of place or unachievable.

Scientific Inquiry and Methodology

The Minnesota standards for scientific inquiry and methodology are included in the "nature of science and engineering" strand, and the standards are generally thorough. For example, first graders are expected to support their claims with observations. Then at the third-grade level, students must be able to question the evidence others provide. At the high school level, this appropriately develops into an expectation for students to be cognizant of the effects of bias, the implications of their assumptions, and professional norms and ethics.

There are some drawbacks, however. Some standards are vague to the point of meaninglessness. For instance, third-grade students are to "understand that everybody can use evidence to learn about the natural world, identify patterns in nature, and develop tools." But surely there is more to scientific inquiry, even at that grade level, than this pious generality.

Though a minor issue, the standards are occasionally marred by an inappropriate focus on local beliefs. Fifth graders, for example, are told that science is "influenced by local traditions and beliefs," a truism that is a poor substitute for the reality that the scientific process aims to negate and overcome such influences in its pursuit of universal knowledge and understanding. The fascination with local traditions extends into high school, where students are asked to consider how "Native American understanding of ecology" has contributed to scientific ideas. No guidance is given as to what may be involved here, nor are any examples provided. The tendency to blur the distinction between scientific and traditional wisdom is not helpful to the students' development of a clear understanding of science.

Physical Science

The physical science standards are barely passable. While some important content is covered, much is missing—or slighted—and the overall impression is of disorganization and a superficial understanding of the subject matter on the part of the writers.

Conservation of mass is among the few topics that are reasonably well covered:

> **Differentiate between kinetic and potential energy and analyze situations where kinetic energy is converted to potential energy and vice versa. (grade 6)**

Unfortunately, such flashes of competence are rare.

Sometimes a disconnect emerges between the content introduced in a standard and the example set forth in the accompanying benchmark. Take, for example, the following from fourth grade:

> **Energy can be transformed within a system or transferred to other systems or the environment.**
>
> - **Demonstrate how an electric current can produce a magnetic force. (grade 4)**

Both statements are true, but the benchmark has nothing to do with the standard.

Other standards simply set unrealistic expectations. Students in sixth grade are, for example, asked to:

> **Use wave properties of light to explain reflection, refraction, and the color spectrum. (grade 6)**

That's a tall order for middle school students, and it doesn't help that it involves several quite diverse explanations involving the law of reflection, Snell's law, and the phenomena of dispersion (for prisms) or diffraction (for diffraction gratings), together with the physiology of color perception.

Occasionally, the standards require mastery of prerequisite content that is never included in previous grades. For example:

> **Explain and calculate the acceleration of an object subjected to a set of forces in one dimension ($F=ma$). (grades 9-12)**

But the student who has had no exposure to kinematics (specifically, the meaning and mathematical manipulation of acceleration) will be able to make nothing of this statement, for kinematics is treated nowhere in K-8 physical science prior to high school, and only very poorly even in high school physics (more on this in the high school physics section below).

Other standards are simply wrong, such as:

> **Glass conducts heat well, but is a poor conductor of electricity. (grade 4)**

No, glass is a poor conductor of heat. Indeed, very few materials conduct electricity poorly and heat well. Persons who are not aware of this property of solids ought not to be writing physical science standards.

High School Physics

The high school physics standards are marred by illogical organization. As noted above, prior to high school there is no discussion of kinematics in one dimension, let alone two. Yet high school physics students are expected to:

> **Use vectors and free-body diagrams to describe force, position, velocity and acceleration of objects in two-dimensional space. (high school physics)**

Then, immediately afterward, students are asked to:

> **Apply Newton's three laws of motion to calculate and analyze the effect of forces and momentum on motion. (high school physics)**

How does this relate to the item immediately preceding? What are we to make of the mention of momentum? And what follows in the next few items is pure chaos. Unfortunately, this typifies the entire treatment of high school physics.

High School Chemistry

The high school chemistry standards are marginally stronger than those for physics, especially the standards covering stoichiometry and solutions. Mathematical calculations, a central component to a rigorous high school chemistry course, are brought to the fore, notably in the standards on percent composition and empirical and molecular formulas. Moles, molar mass, balanced-equation relationships, and molarity are just a few of the topics described by fairly well-written content standards.

The handling of other topics—including chemical bonding, acids/bases, carbon chemistry, and the periodic table—is much weaker. For these, students are expected to understand concepts for which essential prior knowledge has not been specified. For example, students are asked to "relate the properties of acids and bases to the ions they contain and predict the products of an acid/base reaction." But there has been no discussion about ions or properties of ionic solutions—or even expected vocabulary words like "neutralization" or "titration."

No standard asks students to know the kinetic molecular theory itself, but still they are asked to use the theory to explain the "behavior of gases and the relationship among temperature, pressure, volume and the number of particles." This statement—the only standard about gases—is asking about the ideal gas law, but doesn't name the law or use its mathematical expression ($pV = nRT$). Further, the appropriate "moles of gas" is avoided, substituted for "number of particles."

Earth and Space Science

The Minnesota earth and space science standards are reasonably comprehensive, covering the water cycle, mineral properties, fossils, and natural resources. The basic structure of the solar system is also well covered, beginning in third grade with the following:

> **Recognize that the Earth is one of several planets that orbit the sun, and that the moon orbits the Earth. (grade 3)**

This is nicely expanded in eighth grade and in high school, with standards like this one:

> **Recognize that the sun is a medium-sized star, one of billions of stars in the Milky Way galaxy, and the closest star to Earth. (grade 8)**

> **Use the predictable motions of the Earth around its own axis and around the sun, and of the moon around the Earth, to explain day length, the phases of the moon, and eclipses. (grade 8)**

> **Describe how the solar system formed from a nebular cloud of dust and gas 4.6 billion years ago. (grades 9-12)**

A few things are missing, including detail on the workings of earthquakes and volcanoes. And some important content, which could and should be handled in elementary or early middle school, is not introduced until late middle school or high school. For instance, while plate tectonics is well treated, it is not introduced until eighth grade. In addition, while earlier grades do see mention of climate and weather, the distinctions among and origins of sedimentary, metamorphic, and igneous rock are deferred until eighth grade.

Other topics, such as cosmology, push the level of rigor too far:

> **Explain how evidence, including the Doppler shift of light from distant stars and cosmic background radiation, is used to understand the composition, early history, and expansion of the universe. (grades 9-12)**

That is a very big order for a single standard, and will surely overwhelm even the well-prepared high school student.

Life Science

Important life science content is presented quite minimally, but the flow and logic are such as to convey an understanding of the concepts rather than coming across as a list of topics to check off. The inclusion of examples from Kindergarten through eighth grade helps to further explain what students should know and be able to do.

Microbial infections and vaccination—subjects too often omitted from life science standards in Kindergarten through eighth grade—are tackled in eighth grade; their coverage is apt and well done. But while photosynthesis is mentioned in seventh grade, it lacks detail; in addition, there is no mention of respiration. (Both topics, however, are well-covered in high school.)

Similarly, seventh-grade students are asked to:

> **Recognize that cells contain genes and that each gene carries a single unit of information that either alone, or with other genes, determines the inherited traits of an organism. (grade 7)**

Yet there is no indication of what genes are or what they do, nor any mention of the proteins that are specified in the genetic code. Fortunately, these topics are covered in depth in high school.

In general, the high school standards are thorough and rigorous, with many outside-the-usual topics covered, like a continuation of microbial topics and coverage of genetic testing. The high school evolution section is complete and well organized.

Given the equal measures of good and the bad, the Minnesota science standards average out to a middling four out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

For the most part, the presentation of Minnesota's standards is clear—but specificity sometimes suffers. With respect to the latter, the main weakness lies in the physical sciences and the all-too-common mismatches between the standards and the examples given (some of which are described above).

A tendency toward needlessly befuddling language is another failing, particularly when straightforward mathematical concepts are at hand. Consider this demand in the chemistry material:

> **Use the kinetic molecular theory to explain the behavior of gases and the relationship among temperature, pressure, volume, and number of particles. (high school chemistry)**

This expectation could be much more compactly presented as, "Manipulate the equation $pV = nRT$."

Similar fuzziness is evident in the science process offerings. A curriculum founded on these materials would be a hodgepodge that fails to convey a sense of system to the student. Indeed, it would be an invitation to science by memorization. As such, the Minnesota standards earn themselves a one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Mississippi

GRADE	SCORES		TOTAL SCORE
C	Content and Rigor	4/7	5/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**3.8**
Scientific Inquiry & Methodology	2
Physical Science	2
Physics	6
Chemistry	5
Earth & Space Science	5
Life Science	3
Clarity & Specificity	**1.0**

Average numerical evaluations

Overview

The Mississippi science standards are a study in contrast. Some content areas are poorly written and disorganized, while others, notably earth and space science and high school physics and chemistry, are reasonably strong and thorough. An excessive reliance on shorthand—bullet points run rampant throughout the document—deprives the material of depth, making it difficult to imagine that a coherent, effective curriculum might emerge for students in the Magnolia State.

Organization of the Standards

The Mississippi K-8 *Science Framework* is divided first into four strands: inquiry, physical science, life science, and earth and space science. Each strand is then divided into a series of competencies, or standards. These competencies are then elaborated and clarified by means of objectives and sub-objectives. For example, a fifth-grade earth and space science competency asks students to "develop an understanding of the properties of Earth materials, objects in the sky, and changes in the Earth and sky." The related objectives and sub-objectives are as follows:

> **Summarize how weather changes.**
>
> - **Weather changes from day to day and over the seasons**
> - **Tools by which weather is observed, recorded, and predicted. (grade 5)**

Finally, the state assigns a "depth of knowledge" (DOK) level for each sub-objective. There are four DOK levels: recall, skill/concept, strategic thinking, and extended thinking. They are meant to "help administrators, teachers, and parents understand the objective in terms of the complexity of what students are expected to know and do." For example, DOK 1 (recall) states:

> **Level 1 (Recall) includes the recall of information such as a fact, definition, term, or a simple procedure, as well as performing a simple algorithm or applying a formula. Other key words that signify a Level 1 include "identify," "recall," "recognize," "use," and "measure." Verbs such as "describe" and "explain" could be classified at different levels depending on what is to be described and explained.**

The high school standards are organized similarly, except that competencies are presented by course, rather than by grade.

Document(s) Reviewed

- *Mississippi Science Framework*. 2010. Accessed from: http://www.mde.k12.ms.us/acad/id/curriculum/Science/Webpage%20links%207%2031%2008.htm

Mississippi offers an astonishingly large number of standards for high school courses. Along with ninth-grade physical science and physics and chemistry, the state articulates standards for Introduction to Biology, Biology I, Biology II, and seven other life science courses, as well as another seven sets of standards for courses ranging from Organic Chemistry to Aerospace Studies. And this does not include Advanced Placement courses.

Content and Rigor

The Mississippi standards have moments of strength, notably in physics and chemistry. But even for chemistry, the material often suffers from confusion, with some important content omitted entirely.

Scientific Inquiry and Methodology

The brevity of Mississippi's inquiry standards is both a blessing and a curse. In far too many states, process standards take up a disproportionate part of the whole; this is not the case in Mississippi. Unfortunately, the state often errs on the side of *too* brief—many of these standards are so compact that they fail to outline the specific content and skills that students need to learn. For example, Kindergarten students must "ask questions and find answers by scientific investigation," but the six bulleted tasks (e.g., "demonstrate an understanding of a simple investigation by asking questions" and "recognize that when a science investigation is done the way it was done before, very similar results are expected") offer little help as to how the stated competency can be realized in the classroom in the course of teaching content material. This vagueness stretches all the way through the grades; in first grade, one of the six objectives is to "predict the results of an investigation if it is repeated," certainly an objective that can be easily met. Fifth graders are asked to "evaluate results of different data (whether trivial or significant)." We cannot divine what this objective even *means*. Regrettably, similarly content-free standards can be found throughout.

Physical Science

The physical science standards are poorly presented. To begin, the state often throws several unrelated matters into a single confusingly written or scrambled sentence. It is frequently difficult to discern the connection between a single standard and the bulleted items that follow it. Take, for example, the following:

> **Describe physical properties of matter (e.g., mass, density, boiling point, freezing point) including mixtures and solutions.**
>
> - **Filtration, sifting, magnetism, evaporation, and flotation**
> - **Mass, density, boiling point, and freezing point of matter**
> - **Effects of temperature changes on the solubility of substances. (grade 5)**

This standard is a confused mess. In the first bullet, one assumes that students are meant to learn the five techniques that can be used to separate mixtures, though that expectation should be made far more clearly. The second bullet merely repeats information already in the standard itself. And what is expected of students in the third bullet is impossible to discern, especially since increasing the temperature raises the solubility of some substances, but decreases it for others.

Similarly, the following standard crams far too much into a single expectation:

> **Investigate and describe the effects of forces acting on objects.**
>
> - **Gravity, friction, magnetism, drag, lift, and thrust**
> - **Forces affecting the motion of objects. (grade 6)**

Gravity, friction, and magnetism are not forces, though gravitational forces, frictional forces, and magnetic forces are. And it is odd to jam them together with three forces of specific interest in aerodynamics and hydrodynamics. Finally, the second bullet is vague to the point of meaninglessness.

Similar standards can be found throughout.

High School Physics

The high school physics course is quite strong. Though excessively brief (the whole is covered in about three pages), the coverage is systematic, logical, and lucid, beginning with kinematics and dynamics, proceeding to work and energy, and then moving on to oscillations, sound and light, electromagnetism, and modern physics.

The coverage of kinetic and potential energy is also exemplary and is followed by strong and systematic coverage of both momentum and thermodynamics.

The rest of the physics material is quite similar in form and content. In all, these standards create a solid guide for curriculum and textbook developers.

High School Chemistry

The Mississippi science standards touch on most of the essential high school chemistry content students should learn. Unfortunately, that content is often presented in a haphazard and disorganized way. For example, Le Châtelier's principle is introduced before students have been asked to learn about equilibrium. Found only in ninth-grade physical science, electron transitions and atomic spectra belong in chemistry class because they helped explain modern atomic theory. Hydrogen bonding, appropriately, is found in Biology I. But it is not included in Chemistry I, where it also belongs, as an important type of intermolecular force.

Adding confusion, some chemistry standards merely hint at what students should know. Take, for example, the following:

> **Develop a three-dimensional model of molecular structure.**
>
> - **Lewis dot structures for simple molecules and ionic compounds**
> - **Valence shell electron pair repulsion theory (VSEPR). (high school chemistry)**

Missing are the names for the molecular shapes predicted for Lewis dot structures, the connection of these shapes to molecular polarity, and what VSEPR theory is and how it is used. Those who need to use the Mississippi chemistry standards will cry out for more guidance.

Earth and Space Science

The earth and space science content from Kindergarten through eighth grade varies—it is richly ambitious in places and sketchy in others. The standards include much important content, but the presentation is often confusing.

As an example of laudably ambitious material, eighth grade includes some cosmology—a topic normally presented in high school (often ninth-grade) courses:

> **Describe the hierarchical structure (stars, clusters, galaxies, galactic clusters) of the universe and examine the expanding universe to include its age and history, and the modern techniques (e.g., radio, infrared, ultraviolet, and X-ray astronomy) used to measure objects and distances in the universe. (grade 8)**

Unfortunately, the quality is not consistent. For example, the sixth-grade treatment of weather gives only the vague direction that students should:

> **Analyze climate data to draw conclusions and make predictions. (grade 6)**

What, precisely, students should know or be able to do is unclear. Yet in other grades, similar material is spelled out in rich detail.

Plate tectonics includes some important content, but the material is disorganized and sometimes a bit garbled. Minerals get little more than mention in Kindergarten through eighth grade, and though the subject does show up in the high school earth and space science course, it is oddly presented. Further, the rock cycle is not developed.

Life Science

To their credit, the Mississippi standards do not shy away from the term "evolution," which appears extensively throughout the document. Unfortunately, the progression of the subject is not easy to follow at the high school level, as it is scattered through approximately ten life science courses. And perhaps most troubling, students are only required to take one course for high school graduation, leaving little confidence that students will graduate with a firm understanding of this important topic.

Worse, problems of sequence and rigor persist across topics and grade levels, and students are often asked to learn content that is simply inappropriate for their grades. For example, in fourth grade, students are asked to:

> **Compare characteristics of organisms, including growth and development, reproduction, acquisition and use of energy, and response to the environment.**
>
> - **Life cycles of various animals to include complete and incomplete metamorphosis**
> - **Plant or animal structures that serve different functions in growth, adaptation, and survival**
> - **Photosynthesis. (grade 4)**

That material is too advanced for fourth graders.

Then, in sixth grade, students are asked to:

> **Compare and contrast structure and function in living things to include cells and whole organisms.**
>
> - **Hierarchy of cells, tissues, organs, and organ systems to their functions in an organism**
> - **Function of plant and animal cell parts (vacuoles, nucleus, cytoplasm, cell membrane, cell wall, chloroplast)**
> - **Vascular and nonvascular plants, flowering and non-flowering plants, deciduous and coniferous trees. (grade 6)**

Such material is normally addressed at the high school level.

With mixed quality ranging from the very good treatment of physics to the poor treatment of physical science, Mississippi ends up with an average score of four out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Mississippi science standards are disorganized, making it difficult to track the progression of content and rigor from grade to grade. The state provides objectives and sub-objectives, which are meant to clarify what students should know and be able to do, yet the document notes that "*objectives are not intended to be taught in the specific order in which they are presented. Multiple objectives can and should be taught at the same time*" (original emphasis). That's a good thing, because the order of the objectives is often a jumble where some assume knowledge that the standards have not previously explained. Further complicating matters, the assigned depth of knowledge (DOK) indicators often make little sense, making it seem like the standards writers weren't sure what the objectives actually entailed.

In several places, expectations boil down to jarring episodes of boosterism of local agencies and businesses. For example, students are asked to:

> **Develop a logical argument to explain how the forces which affect the motion of objects has [*sic*] real-world applications including (but not limited to) examples of Mississippi's contributions as follows:**
>
> - **Automotive industry (Nissan's new production plant is located in Canton, MS. Toyota's new facility is in Tupelo, MS.)**
> - **Aerospace industry (The Raspet Flight Research Laboratory, housed at Mississippi State University, is one of the premier university flight research facilities in the country.)**
> - **Shipbuilding industry (Ingall's [*sic*] Shipbuilding, of Pascagoula, MS, is a leading supplier of marine vessels to the United States Navy.) (grade 6)**

This poorly written standard gives the illusion that a study of Mississippi businesses will somehow convey an understanding of Newton's second law of motion (the effect of force on motion). It won't.

Unfortunately, confused and confusing writing is commonplace. For example, one standard asks students to compare "seismic wave velocities of earthquakes and volcanoes to lithospheric plate boundaries using seismic data" (grade 8). Whatever was intended here, seismic wave velocities, like those of all mechanical waves, depend only on the medium through which they are passing, and not the source or any boundaries through which they may pass.

Taken together, these drawbacks earn Mississippi a one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Missouri

GRADE	SCORES		TOTAL SCORE
C	Content and Rigor	4/7	6/10
	Clarity and Specificity	2/3	

REPORT CARD

Content & Rigor	**3.7**
Scientific Inquiry & Methodology	5
Physical Science	4
Physics	0
Chemistry	2
Earth & Space Science	5
Life Science	6
Clarity & Specificity	**2.3**

Average numerical evaluations

Document(s) Reviewed

- *Missouri Grade and Course Level Expectations: K-5, 6-8, Biology*. November 2008. Accessed from: http://www.dese.mo.gov/divimprove/curriculum/GLE/
- *Missouri Course-Level Expectations: Other Science Courses*. June 2007. Accessed from: http://www.dese.mo.gov/divimprove/curriculum/GLE/documents/cur-sc-other-cle-1107.pdf

Overview

The Missouri standards present a mixed picture, varying in quality from quite good (for K-8 life science) to essentially useless (for high school physics). Most material lies between these extremes.

Organization of the Standards

The K-8 Missouri standards are first divided into eight strands: matter and energy; force and motion; living organisms; ecology; earth systems; universe; scientific inquiry; and science, technology, and human activity. Each strand is then divided into sub-strands, then into "standards" which are common across all grades. These standards are then explained by grade-specific learning objectives. For example, under the "properties and principles of matter and energy" strand, the first sub-strand indicates that "changes in properties and states of matter provide evidence of the atomic theory of matter." A standard listed under this sub-strand further explains that "objects, and the materials they are made of, have properties that can be used to describe and classify them." And a first-grade learning objective linked to that standard asks students to: "Order objects according to mass."

The high school standards are organized similarly, except that they are presented by course (rather than by grade) for Biology I, Physical Science, Physics I, Chemistry I, and Earth and Space Science.

Oddly, there are standards for high school biology (presented with the K-8 standards) as well as for Biology I (presented with the other high school courses). While the distinction between biology and Biology I is not completely clear, we infer that the former is relevant to the traditional high school biology course, and it is the one considered in this review.

Content and Rigor

The best of the Missouri standards typically appears in the earlier grades. As grade levels rise, the content becomes increasingly prone to error.

Scientific Inquiry and Methodology

The Missouri standards offer a number of refreshing observations, from acknowledging that there is no rigid procedure called "the scientific method" to the consideration that gender and ethnicity can influence scientific conduct. Students are thus presented with a more realistic depiction of the scientific endeavor. Throughout, there is a good dose of realism about the scientific process and the social and historical aspects of the scientific enterprise. Process material builds up gradually, appropriately, and logically across grades.

There is, however, some confusion. Within the "scientific inquiry" strand, one sub-strand states that "the nature of science relies upon communication of results and justification of explanations." The stated expectations, however, deal almost exclusively with presentation of results. The issue of justification is dealt with more properly in the previous sub-strand, which states that "scientific inquiry includes evaluation of explanations (laws/principles, theories/models) in light of evidence (data) and scientific principles (understandings)."

Elsewhere, students are asked to analyze "whether evidence (data) and scientific principles support proposed explanations (laws/principles, theories/models)." But laws don't *explain* anything—they make statements. And theories rise above the status of proposed explanation. A similar confusion arises in one of the historical strands, where hypotheses are conflated with "accepted ideas" such as laws and theories. Disturbingly, this same strand calls on students to "identify and analyze current theories that are being questioned, and compare them to new theories that have emerged to challenge older ones." The examples given—the political whipping boys of global warming and "theories" of evolution—are not theories being questioned within the scientific community; in this case, one must conclude that political considerations have trumped science in the writing of the standards.

Physical Science/High School Physics

From Kindergarten through eighth grade, physical science is generally strong, and the coverage of energy is especially impressive. At elementary levels, the problem of making a satisfactory, usable definition of energy is a knotty one, but Missouri addresses it in an interesting and useful way with the following standard:

> **Forms of energy have a source, a means of transfer (work and heat), and a receiver. (grades K-8)**

In this context, sound is investigated in Kindergarten and second grade, heat in first and third grades, light in third and fifth grades, and electric circuits in fourth grade.

Mechanics is addressed clearly and the standards increase in depth and rigor from grade to grade.

There are some scientific errors, however, and the number of these errors increases as grade levels rise. Take, for example, the following sixth-grade standard:

> **Describe how changes in energy cause changes in loudness and pitch of a sound. (grade 6)**

Loudness is certainly associated with energy density, but pitch is another matter. Frequency does appear in the mathematical expression for energy flux of a wave, but surely this is not what is intended for sixth graders.

Then, in seventh grade, students are asked to:

> **Describe the interactions (i.e., repel, attract) of like and unlike charges (i.e., magnetic, static electric, electrical). (grade 7)**

What that means is anyone's guess. Magnetic forces do not have anything to do with charges, and it is impossible to tell what distinction is intended between "static electric" and "electrical."

The high school physics standards often ask little more than the standards for Kindergarten through eighth grade. For example, a high school standard (listed for high school physical science, Physics I, Chemistry I, and Earth and Space Science) asks students to:

> **Classify the different ways to store energy (i.e., chemical, nuclear, thermal, mechanical, electromagnetic) and describe the transfer of energy as it changes from kinetic to potential, while the total amount of energy remains constant, within a system (e.g., using gasoline to move a car, photocell generating electricity, electromagnetic motor doing work, energy generated by nuclear reactor). (high school)**

This standard is no more sophisticated than what was included in the standards prior to high school.

Similarly, high school students are asked to "describe the force(s) that keep an object traveling in a circular path." But again, this is just a version, stated less clearly, of an earlier standard: "Describe the circular motion of a moving object as the result of a force acting toward the center" (grade 7).

High School Chemistry

Like the high school physics standards, far too many of the high school chemistry indicators ask far too little of students. Take, for example, the following:

> **Calculate the number of protons, neutrons, and electrons of an isotope, given its mass number and atomic number. (Chemistry I)**

Certainly more can be expected of high school students.

Other standards are overly simplistic or trivial. For instance:

> **Classify a substance as being made up of one kind of atom (element) or a compound when given the molecular formula or structural formula (or electron dot diagram) for the substance. (Chemistry I)**

In all, there is simply too little substance in the chemistry standards to guide a rigorous, high school level curriculum.

Earth and Space Science

Overall, the earth and space science standards are well written, logical, and free from obvious error; many topics are addressed with sufficient depth and rigor. Plate tectonics, climate, and weather are all well covered. Content in the elementary grades is quite complete.

But a few items of important content are missing or underdeveloped. For example, although the increasing distances between galaxies is mentioned, the evidence for this expansion and its implications for possible origins of the universe are not explained; the Big Bang gets only a glancing mention in the Impact of Science section.

Relative dating methods are introduced in eighth grade with this entry: "Use evidence from relative and real dating techniques (e.g., correlation of trace fossils, landforms, and rock sequences; evidence of climate changes; presence of intrusions and faults; magnetic orientation; relative age of drill samples) to infer geologic history." But aside from the fact that the term "real" is probably a stab at "absolute," absolute dating methods aren't at all explained. Earthquakes and volcanoes get short shrift for the interesting phenomena they are, mentioned only as hazards and effects of plate tectonics (which get better treatment). There is good reference to evidence of climate change—both natural and human—but, oddly, no explanation of important mechanisms such as the greenhouse effect.

Life Science

Though not perfect, the best coverage by far is in the life sciences. There is a substantial amount of good material in eighth grade on heredity, cells, and physiology. As one example, "Identify and contrast the structures of plants and animals that serve similar functions (e.g., taking in water and oxygen, support, response to stimuli, obtaining energy, circulation, digestion, excretion, reproduction)." Eighth grade also includes solid material on diseases.

At the high school level, an item marked with an asterisk "indicates that it is a local assessment item"—in other words, it will not be covered on the statewide exams. Unfortunately, quite a lot of the material on evolution is treated in this way. For example, the following standards are asterisked:

> **Explain how similarities used to group taxa might reflect evolutionary relationships (e.g., similarities in DNA and protein structures, internal anatomical features, patterns of development).**
>
> **Explain how and why the classification of any taxon might change as more is learned about the organisms assigned to that taxon.**
>
> **Recognize that degree of relatedness can be determined by comparing DNA sequences.**
>
> **Interpret fossil evidence to explain the relatedness of organisms using the principles of superposition and fossil correlation.**
>
> **Evaluate the evidence that supports the theory of biological evolution (e.g., fossil records, similarities between DNA and protein structures, similarities between developmental stages of organisms, homologous and vestigial structures). (Biology I)**

By contrast, the following evolution topics do not have an asterisk:

> **Explain the importance of reproduction to the survival of a species (i.e., the failure of a species to reproduce will lead to extinction of that species).**
>
> **Identify examples of adaptations that may have resulted from variations favored by natural selection (e.g., long-necked giraffes, long-eared jack rabbits) and describe how that variation may have provided populations an advantage for survival.**
>
> **Explain how environmental factors (e.g., habitat loss, climate change, pollution, introduction of non-native species) can be agents of natural selection. (Biology I)**

In other words, all evolution material that might be considered controversial is categorized as being subject to local assessment and thus exempt from wider examination at the state level.

Taken together, the Missouri science standards earn a middling four out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Missouri standards are, for the most part, clearly written. Unfortunately, when they stumble, we find confusing hodgepodges like this: "Identify pure substances by their physical and chemical properties (i.e., color, luster/reflectivity, hardness, conductivity, density, pH, melting point, boiling point, specific heat, solubility, phase at room temperature, chemical reactivity)" (high school).

In addition, the standards vary widely in specificity, and syntax is often at the root of the problem. In physical science, for example, students are asked to:

> **Identify magnets cause some objects to move without touching them. (Kindergarten)**
>
> **Identify magnets attract and repel each other and certain materials. (grade 2)**
>
> **Identify matter is anything that has mass and volume. (grade 6)**

This silliness seems to arise from the misuse of the verb "identify," because it occurs frequently in a variety of contexts. Another example is the standard's frequent error in measuring forces in "Newton's," instead of newtons.

The overall score for clarity and specificity is a respectable but imperfect two out of three. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Montana

GRADE	SCORES		TOTAL SCORE
F	Content and Rigor	1/7	1/10
	Clarity and Specificity	0/3	

REPORT CARD

Content & Rigor	**1.3**
Scientific Inquiry & Methodology	2
Physical Science	1
Physics	0
Chemistry	0
Earth & Space Science	2
Life Science	3
Clarity & Specificity	**0.0**

Average numerical evaluations

Overview

Montana's science content is a thin amalgam of wooly commands and vague expectations. Oases of real information appear, but it's difficult to see how educators could tease more than a few drops of knowledge from the larger mirage.

Organization of the Standards

The standards are divided first into six broad strands (called "standards"). For each, the *Framework* provides "benchmarks" for fourth, eighth, and twelfth grades. These benchmarks are designed to be "check points along the K-12 continuum to assess student progress towards meeting the standards."

In a companion document, the state provides "Essential Learning Expectations for Science" (ELEs) for grades K-12. The ELEs communicate "the necessary content, context, and thinking/reasoning skills students must comprehend and apply along the learning continuum." The ELEs are presented grade by grade for Kindergarten through fifth grade, then in two grade bands: 6-8 and 9-12. Within the grade band covering 9-12, some standards are marked as tenth-grade expectations.

Content and Rigor

The Montana documents are permeated with vague if high-sounding generalities that are of little or no use in setting up a course of study. Although bits of well-developed content appear, these are stranded by poor or nonexistent follow-up and an overall failure to build on knowledge through the advancing grades.

Scientific Inquiry and Methodology

Across all grade levels and bands, the standards addressing scientific inquiry and methodology are vacuous. For instance, in fourth grade, students are expected to recognize that "knowledge is gained through questioning and observations," an empty observation grounded in no real science content. Also in fourth grade, students are asked to "list and discuss environmental problems and concerns." In eighth grade, they are expected to "investigate occupations that use science." To what end, we're never told. Likewise, we are never informed as to what makes science "a human endeavor," but eighth graders are somehow supposed to know.

Document(s) Reviewed

- *Montana K-12 Science Content Standards Framework*. 2006. Accessed from: http://www.opi.mt.gov/pdf/Standards/10ContStds-Science.pdf
- *Montana Essential Learning Expectations for Science*. 2009. Accessed from: http://opi.mt.gov/pdf/standards/09ScienceELE.pdf

One of the six content standards directs students to "understand historical developments in science and technology," but the benchmarks and ELEs within that standard are riddled with errors. For instance, historians and scientists alike will find it puzzling to read that James Hutton discovered the "naturalness of change theory"—a meaningless statement—and that Steno "recognized the importance of rock layers." Important for what, one wonders, as there is no mention of his priority in stating explicitly the basic stratigraphic principle that sedimentary layers form horizontally, the later ones on top of the earlier ones.

Like a number of other states, Montana tries to integrate the experiences of its indigenous peoples into its science standards. And as is too often the case, it never becomes clear how this integration is supposed to aid or develop student understanding of the process and content of science. For example, while first graders may enjoy discussing "Montana American Indians' explanations of the natural world," there is no guidance as to how this would function in the science classroom or build the students' scientific sophistication. The interest in indigenous experiences continues throughout the curriculum and leads to enigmatic expectations, such as, "Define and discuss what constitutes a community, a culture, and a society" (grade 4), or "Identify occupations that use science including Montana American Indians" (grade 4). Both are simplistic and banal, and the latter is poorly written to boot.

Physical Science/High School Physics/High School Chemistry

Some essential physical science content is covered thoroughly and at the appropriate level of rigor. For instance, the concept of gas is introduced in third grade; the distinction among solids, liquids, and gases is emphasized in fourth grade. Energy is introduced in third grade as "the ability to cause change." Refraction and reflection of light are introduced as early as first grade. And basic chemical concepts such as elements, compounds, and mixtures are introduced in fifth grade.

Unfortunately, omissions and errors also plague the standards. For instance, changes of state, introduced in first grade, are confusingly subsumed under the coverage of "energy." Many essential chemical concepts are also missing entirely, including chemical bonding (beyond mere mention), the ideal gas law, acid-base and redox reactions, stoichiometry or the mole concept, and solution chemistry. In fact, a scan of the entire document reveals the word "solution" only in the context of solving environmental problems.

Prerequisite content needed for high school chemistry is inadequate. The entire eighth-grade coverage of chemical topics is contained in the two woefully inadequate benchmarks:

1. **Classify, describe, and manipulate the physical models of matter in terms of: elements and compounds, pure substances and mixtures, atoms, and molecules.**
   a. **Classify matter as atoms, molecules, elements, compounds, pure substances, or mixtures.**
   b. **Identify common element and compounds by their symbol and chemical formula.**
   c. **Create and manipulate simple models of common elements and compounds.**
   d. **Identify the relationship between atoms, molecules, elements, compounds, pure substances, and mixtures.**
2. **Examine, describe, compare, and classify objects and substances based on common physical properties and simple chemical properties. (grade 8)**

An unfortunate by-product of this compression is the stuffing of such very important but diverse concepts of atom, element, and substances into a single, undifferentiated list. And the state never indicates what, precisely, the student is to know about each.

There are also outright errors, including the following:

> **Explain the relationship between changes in thermal energy and states of matter (e.g., increase/decrease of thermal energy = change in state).**
>
> **Recognize that temperature measures the average kinetic energy of particles in a substance. (grade 8)**

There is a failure here to make the fundamental distinction between kinetic and potential energy, let alone apply them to the kinetic theory.

The standards contain no specific coverage of high school physics or chemistry courses. Rather, there is a hodgepodge of physical science material in high school, much of it noted as tenth-grade expectations. The level of sophistication expected varies wildly from item to item, with no real system to their organization. For example,

> **Explain how the molecular geometry of a molecule (e.g., water) affects polarity and cohesive/adhesive properties. (grade 10)**

That's a pretty sophisticated task, rendered impossible by the fact that the standards neither ask students to be able to draw

Lewis dot structures for simple molecules nor use these dot structures to predict molecular geometry.

There is much throwing-around of high-sounding phrases that are so general as to be useless. One example is this twelfth-grade requirement:

> **Identify, measure, calculate, and analyze relationships associated with matter and energy transfer or transformations, and the associated conservation of mass. (grade 12)**

One might just as usefully (and more succinctly) condense the entire standard into the statement: "Think about scientific stuff."

Earth and Space Science

The coverage of earth and space science is equally poor and the standards just as vague. We are subjected to such vapidities as, "Compare and contrast the characteristics of Earth's natural features" (grade 4), or "Model and explain the internal structure of the earth and describe the formation and composition of earth's external features in terms of the rock cycle and plate tectonics and constructive and destructive forces" (grade 8).

Life Science

In the *Framework*, the word "evolution" and its variants appear only in four places. And the definition given in the glossary at the end is this:

> **Evolution – A process of change that explains why what is seen today is different from what existed in the past; it includes changes in the galaxies, stars, solar system, Earth, and life on earth. Biological evolution is any genetic and resulting phenotypic change in groups of organisms from generation to generation.**

This definition is far too sketchy to be of any pedagogical use. The term "natural selection" appears only once in the *Framework*, and only in a twelfth-grade benchmark. While it does appear more frequently (eight times) in the *Essential Learning Expectations* document, that coverage is primarily presented through tenth-grade expectations and is woefully inadequate. For instance, students are introduced to fossils in fourth grade, and these are explicitly linked to "past life"—the standards never make it clear that evolution is the unifying principle of the life sciences.

To make matters worse, we see hints of creationism in the use of the term "scientific theory," which appears *only* in the context of such subjects as cosmology and the fossil record. Students are instructed, for example, to "explain scientific theories about how fossils are used as evidence of changes over time" (grade 12) but not to explain scientific theories about how the periodic table predicts chemical similarities.

Pussyfooting around evolution is not the only weakness in the life science standards. Critical content is also missing. For instance, the documents contain no mention of physiology—no muscles, nerves, digestion, nothing. The most we get are the following standards from fourth grade and high school, respectively:

> **Identify that animals have systems for certain functions; explain the relationship between basic animal systems and their functions. (grade 4)**
>
> **Compare and contrast major animal phyla. (grade 10)**
>
> **Compare and contrast body systems between major animal phyla. (grade 10)**

The content here falls seriously short of a decent basis for a K-12 science education. With only glimmers of adequacy, the result is an average score of one out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

Montana's science standards are as poorly written as they are ambiguous. Typos and misspellings are rampant. Many statements are garbled. Sentences run on, seemingly at their own will. The order of presentation is inconsistent and at times illogical. And there is vagueness throughout. To give just one example:

> **Describe how scientific inquiry has produced much knowledge about the world and a variety of contributions toward understanding events and phenomenon [*sic*] within the universe. (grade 4)**

The Montana standards are among the poorest we have evaluated—they earn a zero out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Nebraska

GRADE	SCORES		TOTAL SCORE
F	Content and Rigor	1/7	2/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**1.3**
Scientific Inquiry & Methodology	0
Physical Science	4
Physics	0
Chemistry	0
Earth & Space Science	2
Life Science	2
Clarity & Specificity	**1.3**

Average numerical evaluations

Overview

The Nebraska science standards are inadequate in nearly every way. They lack sufficient depth and breadth at every grade span, and critically important areas receive woefully inadequate attention—or are completely absent.

Organization of the Standards

The Nebraska science standards are constructed in four strands: inquiry, physical science, life science, and earth/space science. Each strand is then divided into sub-strands and finally into standards. Nebraska does not provide grade-specific standards. Instead, standards are provided for four grade bands: K-2, 3-5, 6-8, and 9-12.

An additional document, the *Sample K-12 Science Curriculum*, assigns the standards found within the *Science Standards* grade bands to specific grades, though it states that districts have the option of changing the order of presentation. In addition, the document provides "content boundaries" for the standards, which include limits on "examples, types of measurement, clarifications, appropriate vocabulary, and exclusions for various science concepts and skills."

Content and Rigor

The K-8 physical science materials are the best that Nebraska's science standards have to offer. Unfortunately, they are barely passable, and everything else is worse. Great chunks of critical content are missing, while what's present is often pitched well below a reasonable grade level, weakly developed, or simply wrong.

Scientific Inquiry and Methodology

The scientific inquiry and methodology standards are essentially useless. Students in grades 3-5 are, for example, asked to "recognize many different people study science." Similarly, students in grades 6-8 are asked to "describe how scientific discoveries influence and change society." In neither case do the standards give any indication of what, specifically, students should know.

Students in grades 3-5 are also expected to "provide feedback on scientific investigations," but no guidance is provided as to what that may entail or what formal

Document(s) Reviewed

- *Nebraska Science Standards*. October 2010. Accessed from: http://www.education.ne.gov/science/
- *Sample K-12 Science Curriculum*. 2011. Accessed from: http://www.education.ne.gov/science/

concepts regarding science as a process are to be used. By grades 6-8, students move on to providing "appropriate critique of scientific investigations." And by high school, they are asked to "evaluate scientific investigations and offer revisions and new ideas as appropriate"—a tall order that is grounded in no real content.

Scanning the standards across grades, it is difficult to detect meaningful changes or a development of content. For example, in grades 3-5, students "ask testable scientific questions," yet not until grades 6-8 are students supposed to "formulate testable questions that lead to predictions and scientific investigations." One wonders whether the writers have a clear idea of what "testable" means.

Physical Science/High School Physics/High School Chemistry

The physical science material starts off well enough at the primary grades and progresses in depth through the grade spans covering Kindergarten through eighth grade. But at the high school level, the standards suffer a serious drop in quality—one might call it a collapse. The progression of the treatment of kinematics will serve as an example. Beginning in the grade band covering Kindergarten through second grade, students are asked to:

> **State location and/or motion relative to another object or its surroundings (in front of, behind, between, over, under, faster, slower, forward and backward, up and down)**
>
> **Describe how objects move in many different ways (straight, zigzag, round and round, back and forth, and fast and slow). (grades K-2)**

Then in successive grades, we find:

> **Describe motion by tracing and measuring an object's position over a period of time (speed). (grades 3-5)**
>
> **Describe motion of an object by its position and velocity. (grades 6-8)**
>
> **Describe motion with respect to displacement and acceleration. (grades 9-12)**

This sequence begins as a nice progression from simple qualitative observation of position and general types of motion, through more specific observation, to formal consideration of position and velocity. But then the high school standard is nothing more than an introduction of the term "displacement," with a substitution—rather than a supplementation—of acceleration for velocity. The standard gives no mention of anything quantitative—unacceptable for any high school course—let alone the kinematic equations essential to a physics course.

Throughout all grade spans, adequate space and attention are devoted to Newton's laws. Each receives a separate indicator in the appropriate grade spans, immediately followed by indicators addressing universal forces—magnetic, gravitational, and electrostatic.

Still there are some errors. Notably, Coulomb's law is stated incorrectly:

> **Recognize that an attractive or repulsive electric force exists between two charged particles and that this force is proportional to the magnitude of the charges and the distance between them. (grades 9-12)**

In fact, the force is *inversely* proportional to the *square* of the distance—a crucial difference. And, in a regrettable display of consistency, the same error is seen in the discussion of the universal law of gravitation. This sloppiness is attributable, at least in part, to the careful avoidance of any mathematical expressions and the substitution for verbal circumlocutions that are prone to error.

There are no separate standards for high school chemistry or physics. Some of the high school physical science entries might be construed as such, but the level of the material seems more appropriate for a physical science course in middle school or junior high. This is particularly true for the material on thermal physics introduced at the high school level.

The standards on energy are fairly clear, but the concepts of kinetic and potential energy are similarly deferred until high school. More problematic, the standards contain no single definition of energy; without a good understanding of what energy is, discussing energy conservation (which these standards stress) is a futile exercise.

Chemistry is given cursory—that is, grossly inadequate—treatment at the high school level. The periodic table gets but a single mention. And the important topic of chemical bonding is reduced to just one brief statement about ionic and covalent bonding: "Recognize bonding occurs when outer electrons are transferred (ionic) or shared (covalent)" (grades 9-12). Likewise, acids and bases (which we are told transfer hydrogen ions) and oxidation and reduction reactions (which transfer electrons) are also found together in just one standard: "Recognize a large number of chemical reactions involve the transfer of either electrons (oxidation/reduction) or hydrogen ions (acid/base) between reacting ions, molecules, or atoms" (grades 9-12). Many other necessary content topics are also either inadequately addressed or missing completely. These topics include moles and stoichiometry, carbon chemistry, equilibrium, rates of reaction, solutions, gas laws, and molecular shape and polarity. With so much basic content missing, it would be a mistake to say that there is a course in chemistry outlined in the physical science standards.

Earth and Space Science

While some important earth and space science content is included from Kindergarten through eighth grade, serious gaps plague Nebraska's standards. For instance, while motion in the solar system is well covered, galaxies aren't mentioned anywhere. Nor are the effects of plate tectonics, other than in this amazingly broad standard:

> **Compare and contrast constructive and destructive forces (deposition, erosion, weathering, plate motion causing uplift, volcanoes, earthquakes) that impact Earth's surface. (grades 6-8)**

Similarly, a few grades earlier, students are asked to:

> **Recognize the difference between weather, climate, and seasons. (grades 3-5)**

There is nothing here about climate changes over time.

In the *Sample Curriculum* document, the earth and space science standards for high school are distributed between physical science and biology, the only two subjects that are listed outside of the standards for Kindergarten through eighth grade. Evaluating the dispersed earth and space science standards, we find that astronomy outside our own solar system is especially weak. The word "galaxy" does not appear. Further, there is little or no mention of plate-tectonic processes and effects, the workings of earthquakes and volcanoes, or the evidence for important theories such as the Big Bang.

Life Science

The life science standards are vapid and lifeless. There is only a moment of substance, which appears in the *Sample Curriculum* treatment of cellular composition of organisms, where seventh-grade students are directed to:

> **Identify the organs and functions of the major systems of the human body and describe ways that these systems interact with each other.**
>
> - **The major systems of the human body include: circulatory, digestive, endocrine, excretory, immune, integumentary, nervous, muscular, reproductive, respiratory, and skeletal. (grade 7)**

While the standard should more specifically explicate "the ways that these systems interact with each other," it is reasonably specific and includes much critical content. Unfortunately, such specificity is atypical. Other critical topics are so vague that one cannot assess their level of coverage. For instance, a high school standard asks students to "describe how an organism senses changes in its internal or external environment and responds to ensure survival" (grades 9-12).

Meiosis, mitosis, and Mendelian genetics appear nowhere from Kindergarten through eighth grade.

Even at the high school level, here is all we find regarding Mendelian genetics:

> **Describe that [*sic*] sexual reproduction results in a largely predictable, variety of possible gene combinations in the offspring of any two parents. (grades 9-12)**

The word "evolution" is missing entirely before high school, and its coverage in the high school standards is woefully inadequate, as shown below:

> **Identify different types of adaptations necessary for survival (morphological, physiological, behavioral).**
>
> **Recognize that the concept of biological evolution is a theory which explains the consequence of the interactions of: (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) the ensuing selection by the environment of those offspring better able to survive and leave offspring.**
>
> **Explain how natural selection provides a scientific explanation of the fossil record and the molecular similarities among the diverse species of living organisms.**
>
> **Apply the theory of biological evolution to explain diversity of life over time. (grades 9-12)**

This set of four standards provides a basis—albeit a minimal one—for the study of evolution. Unfortunately, it presents evolution as a topic separate from other biological matters rather than as the founding principle of the discipline. Note also the phrase "the theory of biological evolution." While technically accurate—there exist both the fact of evolution and the theory that explains the fact—this statement often reflects the creationist misuse of the everyday meaning of theory, as in "evolution is *only* a theory, and because it cannot be proven is therefore equivalent or inferior to other constructs." Note that the essential meaning of the second standard would be fully conveyed by the succinct "Recognize that evolution explains..."

Taken as a whole, Nebraska's science standards do not articulate nearly enough of what students need to know and be able to do. They earn an average score of one out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Nebraska standards usually avoid garbled language, but only because they say woefully little. The failure of the material to cover so many integral areas of science erodes its ability to be specific.

Take, for example, the following standard in earth and space science, in which the word "minerals" makes a mere cameo appearance:

> **Describe the characteristics of rocks, minerals, soil, water, and the atmosphere. (grades 3-5)**

Two things might be true here: Either the standards don't care much about these topics, or the authors were at a loss for ways to flesh out these concepts. Neither is reassuring, because both all but guarantee that Nebraska students will not receive adequate instruction in these topics.

As the life sciences section presented above demonstrates, the writers of the Nebraska standards do understand the importance of detail. Why, then would they settle for expectations like this one, in high school: "Describe how an organism senses changes in its internal or external environment and responds to ensure survival"? Such a passage, and the many others like it strewn throughout the rest of the document, begs for more information—and providing it would not have been a heavy lift.

This overall vagueness results in a score of one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Nevada

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	2/7	3/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**1.8**
Scientific Inquiry & Methodology	0
Physical Science	4
Physics	0
Chemistry	0
Earth & Space Science	4
Life Science	3
Clarity & Specificity	**1.3**

Average numerical evaluations

Document(s) Reviewed

- *Nevada K-12 Science Standards*. 2007-08. Accessed from: http://www.doe.nv.gov/Standards_Science.html
- *Nevada Science Achievement Indicators*. 2007-08. Accessed from: http://www.doe.nv.gov/Standards_Science.html

Overview

The Nevada science standards are lamentably brief. Complicating matters, educators must piece together information from two separate and confusing documents to form a complete picture of what students must know and be able to do. Altogether, the materials furnish a very shaky foundation in the sciences.

Organization of the Standards

A table totaling thirteen pages constitutes the complete set of K-12 science standards for Nevada. Within this table, the standards are first divided into four strands: nature of science, earth and space science, physical science, and life science. Each strand is then divided into content standards (or sub-strands), and finally, benchmarks are provided for each of four grade bands: K-2, 3-5, 6-8, and 9-12.

Along with these overly concise standards, the Silver State presents four documents listing science achievement indicators aligned to the benchmarks and organized into the same grade bands. These indicators explain what students in each grade band should know and be able to do across four achievement levels: emergent/developing, approaches, meets, and exceeds.

Content and Rigor

The Nevada science standards suffer from the twin flaws of not offering enough content and bungling what little information they provide. None of the content areas is well covered and strengths are difficult to find. The lack of rigor is particularly appalling in high school—often, even at the “exceeds” level.

Scientific Inquiry and Methodology

The material on scientific inquiry and methodology is rife with platitudes but provides no guidance for what students should know or be able to do. For example, one standard asks students to “identify scientists as people.” (As opposed to what, one wonders?) Elsewhere, the flaws are graver. Students in Kindergarten through fifth grade should “understand that many people, from all cultures and levels of ability, contribute to the fields of science and technology.” Well, yes, but the same can be said of contributors to professional football.

This sort of woolliness is exacerbated by the writers' steadfast aversion to the discussion of concepts—such as theory or hypothesis—that are essential to understanding what science involves and whether everyone can contribute to that enterprise. The term "theory" is introduced only in relation to specific theories (e.g., "theory of evolution") and not as a general concept within science. "Hypothesis" doesn't appear anywhere.

Physical Science/High School Physics/High School Chemistry

The writing is simplistic and pitched at a low level, and often concepts are presented that have not been defined previously in the document. Examples include heat of formation, solubility, entropy, and density. A few topics, like conservation of mass and the properties of solids, liquids, and gases, are repeated grade span after grade span.

Nothing in the documents is appropriate to a high school physics course, nor is any distinction made between a ninth-grade physical science course and a higher-level physics or chemistry course. One might stretch one's imagination and infer that the "meets" level is intended for a ninth-grade physical science course and the "exceeds" level is geared to higher-level chemistry and physics courses. But it is odd indeed to build a course around "exceeded" expectations. Here is a typical example of the difference between the two columns:

> **Meets: Describe the motion of an object using Newton's Laws.**
>
> **Exceeds: Calculate force, acceleration, time, and velocity to accurately predict the motion of an object. (grades 9-12)**

But even the "exceeds" benchmark lacks sufficient detail to be useful for a physics course.

The standards addressing elements of chemistry, like those for physics, are noteworthy more for what's missing than for what's included. They make no reference to atomic models, or ionic, covalent, metallic, or hydrogen bonding. There is one reference to spectra, in the context of identifying substances, and one mention of bonding by electron sharing or transfer. There is nothing about moles or stoichiometry, and just a brief mention of writing and balancing simple equations.

Earth and Space Science

Earth and space science suffers from a generally weak presentation. Though concise and containing few errors, the standards are often too broad to be rigorous, as in the following example:

> **Compare the characteristics of planets in our solar system. (grades 6-8)**

Another problem is that many of the specific content expectations are relegated to the achievement indicators, where the rigor of the expectations is often poorly calibrated. Often, the "emergent" and "approaches" levels are so trivial as to be almost insulting: Students in sixth through eighth grades, for example, are considered to be "approaching" one standard if they merely "understand that Nevada's weather changes." That said, the upper levels of the rubric are sometimes no better. For example, in the third through fifth grades, the student who "exceeds" expectations need only "explain how fossils are evidence of extinct species." And, ironically, there are occasions when the entries on the lower levels of the rubric might be more difficult than the higher ones. In third through fifth grades, an "emergent" standard asks students to "explore fossil formation," a complex task, while the "meets" expectation asks student to "describe how fossils are evidence of past life," the definition of a fossil.

Despite these shortcomings, however, the Nevada earth and space science standards contain few errors. Though they lack the depth needed for a strong set of standards, they cover almost all necessary content, with the water cycle and treatment of the Earth's layers handled particularly well.

Life Science

The life science offerings are vaguely presented and scanty in content. The words gene and chromosome are never used; there is no mention of photosynthesis or any other metabolism. Understandings about cellular and physiological function at the high school level are glosses ("explain the relationship between cell functions and major cell structures"; "discuss the levels of organization specialized to the human anatomy"; "describe the different organ systems in the human body"); it is impossible to evaluate what students will actually be taught, or be expected to know, from such statements.

Far too often, confusion reigns. For example, in sixth through eighth grades, the student who "meets" expectations, according to the achievement indicators, can explain that genetic information is passed from one generation to the next, while the student who "exceeds" expectations can identify DNA as the site of genetic information.

In addition, the standards are fraught with errors. For instance, in sixth through eighth grades, students are to learn that "multicellular organisms can consist of thousands to millions of cells working together." In fact, it's usually hundreds of millions to trillions. Then in grades nine to twelve, the "meets" level student is asked to "explain that DNA is the template to assemble proteins." In reality, however, DNA encodes the sequence of amino acids in a protein.

The treatment of evolution is mixed at best. In the elementary and middle school grades, we have a list of banalities—from students knowing that "differences among individuals within a species give them advantages and/or disadvantages in surviving and reproducing" (grades 3-5), to students knowing that "fossils provide evidence of how life and environmental conditions have changed throughout geologic time" (grades 6-8).

Things improve a bit in high school. There, students are expected to know that "organisms can be classified based on evolutionary relationships," that "similarity of DNA sequences gives evidence of relationships between organisms," and that "the fossil record gives evidence for natural selection and its evolutionary consequences." Students are also expected to know that "the extinction of species can be a natural process" and that "biological evolution explains diversity of life," as well as to know "the concepts of natural and artificial selection." And in the achievement indicators, students are explicitly asked to "classify organisms using evolutionary relationships, including DNA evidence." Though overly broad, this sentence implies a host of useful activities.

Taken as a whole, the science content is poor to absent, earning Nevada an average score of two out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

Despite its rather elaborate system for charting progress, the Nevada standards are mired in confusion and will do little to aid curriculum builders or teachers. The gradations at times seem artificial or forced, with meaningful distinctions rarely made between achievement levels.

Take, for example, the K-2 content standard shown in Figure 1. Will any student in Kindergarten, first, or second grade not know that animals and plants have differences? Will any achieve the "meets" level who cannot manage the "exceeds" level?

Other times, however, the jumps between achievement levels seem unachievable. For instance, in third through fifth grades, a student who can describe heat conduction meets expectations, but it takes understanding of conduction, convection, and radiation to exceed them.

Figure 1. Content Standard L.2.A.2 (grades K-2)

L.2.A.2 Students know differences exist among individuals of the same kind of plant of animal. [*sic*]	
Emergent/Developing	**Recognize that animals and plants have differences.**
Approaches ...	**Describe differences among animals and plants.**
Meets ...	**Describe differences among individuals of the same kind of animal or plant.**
Exceeds ...	**Provide examples of differences among individuals of the same kind of plant or animal.**

Further complicating matters, there is often no clear relation between the benchmark and the achievement indicators or between one indicator and the next, making it nearly impossible for a teacher to discern what, specifically, he should be teaching at each grade level. Yet the achievement indicators provide *more* detail than can be found in the skimpy benchmarks themselves.

Like the content standards, the indicators comprise a bewildering jumble. For example, students in grades six through eight are asked in a single indicator to "distinguish between an open and a closed circuit" and gain "ability to describe kinetic energy." How does the trivial task of distinguishing between an open and closed circuit concern a discussion of kinetic energy? And then later, the vague directive to identify density as one of the "properties of matter" (grades 6-8) would be better described as "know that the ratio of an object's mass divided by its volume is called density and that density is a physical property of matter."

The Nevada science standards are disappointing, at best. The meager detail provided by the achievement indicators helps Nevada eke out an average score of one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

New Hampshire

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	3/7	4/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**2.7**
Scientific Inquiry & Methodology	2
Physical Science	4
Physics	0
Chemistry	0
Earth & Space Science	4
Life Science	6
Clarity & Specificity	**1.0**

Average numerical evaluations

Document(s) Reviewed

- *New Hampshire K-12 Science Literacy Curriculum Framework.* 2006. Accessed from: http://www.education.nh.gov/instruction/curriculum/science/documents/framework.pdf
- *New Hampshire Science Grade-Level Expectations, K-8.* 2006. Accessed from: http://www.education.nh.gov/instruction/assessment/necap/gle.htm#science
- *New Hampshire Science High School Grade-Span Expectations.* 2006. Accessed from: http://www.education.nh.gov/instruction/assessment/necap/gse.htm#science

Overview

The New Hampshire science standards are ambitious but undisciplined. The lower grades generally are good, but the quality declines as the grade level rises. Topics appear willy-nilly, leaving glancing blows but few direct hits, and the document makes unspecified but complicated requests of students. Bad writing, from imprecise science to poor grammar, does further damage.

Organization of the Standards

The New Hampshire standards are divided first into four strands: earth space science, life science, physical science, and science process skills. Each strand is then divided into sub-strands. Finally, for all strands except "science process skills," standards are presented for six grade spans: K-2, 3-4, 5-6, 7-8, 9-11-basic, and 11-12-advanced. (Standards addressing "science process skills" are presented for only three grade spans: K-4, 5-8, and 9-12.) These standards are also accessible through a series of individual grade-span documents as well as individual-strand documents.

The standards are introduced with a single page that describes important theories—a good idea that is poorly executed and adds little value to any of the content areas. The state also provides a series of "advanced" standards for grades 11-12. There is a grade-level overlap with the standards specified for grades 9-11, and the document never clarifies for whom the advanced-level standards are intended.

Content and Rigor

The New Hampshire standards suffer from a split personality. Some topics—life science, in particular—are covered thoughtfully, thoroughly, and with the appropriate level of rigor. Other topics, however, are missing critical content, and/or the level of rigor is inappropriate for the grade level.

Scientific Inquiry and Methodology

Troublingly, more than a quarter of the 125-page *Framework*—thirty-two pages—is devoted to science process skills, including inquiry and methodology. (By comparison, all of physical science is presented in only twenty-one pages.) Devoting so much space to this material inappropriately prioritizes process over content. Worse, the standards themselves are generally vacuous statements that provide little guidance about what students should learn about scientific inquiry, methodology, or history. For example, a section comparing "ways of knowing" offers simplistic statements that confuse the relationship between science and "philosophic knowledge." Most modern philosophers would, for example, deny that "supernatural forces and viewpoints" are logical "philosophical explanations" (whatever that means).

In addition, the social and historical aspects of science receive scant attention.

Physical Sciences/High School Physics/High School Chemistry

The physical science concepts introduced in from Kindergarten through fourth grade are thoughtful, clearly and correctly expressed, and appropriately suited to their grade levels; they challenge students without expecting too much from them. Unfortunately, though the document remains functional, these laudable characteristics fade in the standards for the upper grades. Starting in fifth and sixth grades, the *Framework* falls victim to illogical ordering, inadequate development, and sloppy writing. Take, for instance, this nonsense:

> **Identify energy as a property of many substances. (grades 5-6)**

Other statements are simply inaccurate, such as:

> **Explain that sound vibrations move at different speeds. (grades 5-6)**

Of course, sound vibrations do *not* move at different speeds in the same medium!

There are also unrealistic expectations, such as this one:

> **Use data to determine or predict the overall (net) effect of multiple forces (e.g., friction, gravitational, magnetic) on the position, speed, and direction of motion of objects. (grades 7-8)**

On the chemistry side of physical science, hydrogen bonding, metallic bonding, Lewis dot structures, polarity, molarity, stoichiometry, and equilibrium are all missing. Further, oxidation gets short shrift; it is narrowly defined in eighth grade and never mentioned again.

This trend continues in high school. Consider the treatment of heat energy:

> **Describe the relationship between heat and temperature, explaining that heat energy consists of the random motion and vibrations of atoms, molecules, and ions; and that the higher the temperature, the greater the atomic or molecular motion. (grades 9-11)**
>
> **Explain the concept of entropy. (grades 11-12)**

The first of these two statements is all that the "basic" standards for grades nine through eleven have to say about thermodynamics. This is utterly inadequate. It adds insult to injury to append the second "advanced" statement, which is surely incomprehensible without a prior discussion of the laws of thermodynamics (especially the second law). Its only possible function is to put the reader in awe of writers who know the magical word "entropy."

There is no coverage of high school physics or chemistry.

Earth and Space Science

Earth and space science receives uneven attention. Much is good; the treatments of soils, the evolution of the atmosphere, geologic time measurement, and stellar evolution are sound. But missing entirely are such fundamentals as the solar system as part of a galaxy, volcanism, the greenhouse effect, air pressure (though a "tools" section mentions using a barometer, a string search turns up only one mention of pressure, after the word "blood"), and the distinction between climate and weather.

Fossils are presented as a recurrent theme in earth sciences. Likewise, the related life science theme "Humans are similar to other species in many ways, and yet are unique among Earth's life forms" is well developed and includes good consideration of disease mechanisms—a subject strangely absent from most state standards.

Life Science

The life science standards are well conceived and progress appropriately through the grades. As mentioned above, disease mechanisms are laudably introduced in fifth and sixth grades, beginning with:

> **Explain that the human body has ways to defend itself against disease-causing organisms and describe how defenders, including tears, saliva, the skin, some blood cells and stomach secretions support the defense process. (grades 5-6)**

The content builds nicely on this foundation, both within this grade band and also in the later grades.

New Hampshire also clearly prioritizes evolution in its standards, beginning with the introduction of the *Framework*. To preempt any distortion of the validity of evolution as being "just a theory," the document offers a straightforward list, with brief descriptions, of several other major scientific theories, from gravity to the Big Bang. Further, evolution is introduced early:

> **Recognize that some plants and animals, which are alive today, are similar to living things which have become extinct, such as elephants and mammoths. (grades K-2)**

In seventh and eighth grades, genes and chromosomes are introduced, as are embryological concepts. Some human embryology is included—which is both atypical and laudable. Even more impressively, humans are put into the evolutionary context.

Still, even in a state that handles evolution well, the rare creationist ploy sneaks in. Two Granite State standards ask students to support *or refute* the Big Bang theory (in earth space science) and the genetic relationships among groups of organisms (in life science).

Further, some of the benchmarks are too broad to be useful. For example:

> **Describe the interaction of living organisms with non-living things. (grades 3-4)**

The high school standards are well conceived, with clear, broad, and challenging development of content. There is one unfortunate exception: Mitosis and meiosis are segregated out into the "advanced" eleventh- and twelfth-grade standards, while Mendelian genetics and Punnett squares are explained in the "basic" ninth- through eleventh-grade standards. Teaching Mendelian genetics without an understanding of meiosis would be impossible.

Overall, the major oversights noted above earn New Hampshire an average score of three out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

New Hampshire prides itself on straight talk—it's hard to beat "live free or die" for pithiness. But that directness is often missing from the state's science standards, where vague expectations make it difficult to divine what the document intends to convey. For example:

> **Explain the complete mole concept and identify ways in which it can be used, such as to differentiate between actual and relative mass. (grades 11-12)**

Similarly, students are asked to "understand how the Nebular Hypothesis, fusion, and the process of differentiation contributes [*sic*] to the structure and organization of the universe" (grades 11-12). We are at a loss to understand how a hypothesis might contribute to a structure.

This muddiness also pervades the material on scientific inquiry and methodology, where the standards merely present a series of goals with little guidance as to how to articulate them in the classroom.

The one exception is in the area of life science, where the standards are clear and the content progresses well from grade to grade. New Hampshire's strong treatment of the life sciences buoys the state's clarity and specificity score, leaving the Granite State with a one out of three in this realm. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

New Jersey

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	2/7	3/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**1.5**
Scientific Inquiry & Methodology	0
Physical Science	4
Physics	0
Chemistry	0
Earth & Space Science	4
Life Science	1
Clarity & Specificity	**1.0**

Average numerical evaluations

Overview

New Jersey's science standards are straightforward and complete at the lower grades. Unfortunately, they are tainted by a lack of appropriate follow-through. Instead of clarifying or augmenting the standards, the supplemental classroom material muddles them, and does more harm than good by introducing errors.

Organization of the Standards

New Jersey's science standards, collectively termed "learning progressions," are divided first into four strands: science practices, physical science, life science, and earth systems science. Each strand is then divided into sub-strands, and finally into "cumulative progress indicators" (CPIs), which indicate what students should be able to do by the end of pre-K and the end of grades 2, 4, 6, 8, and 12. (Note that the "science practices" strand lists expectations only for pre-K and the end of grades 4, 8, and 12.) Finally, the state provides a "content statement" that further explains each CPI.

To offer more instructional guidance to teachers, the Garden State provides a series of classroom application documents, which offer sample assessments and resources to accompany each standard. These denote what students should know and be able to do by the end of grades 4, 8, and 12 for the "science practices" strand, and by the end of grades 2, 4, 6, and 8 for the other three strands. These documents are organized in much the same way as the "learning progression" documents, though they also feature common student misconceptions, sample assessment items, a list of web-based resources, and more.

At the high school level, New Jersey further supplements standards with a series of core content clarification documents for high school biology, environmental science, and earth systems science. (No such supplemental material is offered for high school physical science, physics, or chemistry, though the state is currently writing material for each of these subjects.) These clarification documents contain the same types of information—sample assessment items and classroom activities—as the preK-8 classroom applications documents.

Document(s) Reviewed

- *New Jersey Science Standards Learning Progressions*. 2009. Accessed from: http://www.state.nj.us/education/aps/cccs/science/frameworks/2009progressions.pdf
- *New Jersey Science Classroom Applications Documents*. 2009. Accessed from: http://www.nj.gov/education/cccs/cad/5/
- *New Jersey High School Biology/Life Science, Earth Systems Science, and Environmental Science Core Course Content*. 2009-2011. Accessed from: http://www.nj.gov/education/aps/cccs/science/

Content and Rigor

New Jersey's science standards are, in a word, vapid. The bare-bones content that is covered is largely overshadowed by the supplemental materials, which introduce non sequiturs, misleading statements, and full-on errors into the standards. Worse yet, any glimmer of straightforward or rigorous curriculum at the K-8 level disappears by high school, where scant grade-appropriate content can be found.

Scientific Inquiry and Methodology

The scientific inquiry and methodology standards are virtually useless. The state presents four jumbled "science practices": understand scientific explanations; generate scientific evidence through active investigations; reflect on scientific knowledge; and participate productively in science. Worse, nowhere in the text does the word "hypothesis" (or any of its cognates) appear. Instead, students are asked to "pose theories"—a clear indication that the authors have confused theory with hypothesis.

The content and skills also fail to progress from grade to grade. By the end of fourth grade, students are asked to use evidence "to construct and defend arguments." By eighth grade, they are to collect evidence "carefully"; by the end of high school they are to collect "empirical evidence." The difference among these expectations is impossible to discern. And sadly, these are the norm, rather than the exception.

Physical Science/High School Physics/High School Chemistry

Physical science is the high-water mark for the New Jersey standards, but that's not saying much because the coverage of important content is severely uneven.

The standards do address some critical content clearly and with sufficient depth and rigor. A fairly serious treatment of mechanics begins in fourth grade. Thermodynamics is also well explained. Take, for example, the following:

> **Energy can be transferred from one place to another. Heat energy is transferred from warmer things to colder things. (grade 4)**

This is supplemented in the ancillary documents with:

> **Instructional Guidance**
> ***To assist in meeting this CPI, students may:***
>
> **Investigate and describe what happens when an object of higher temperature is placed in direct contact with an object of lower temperature. Record data and use the data to describe which way the heat energy is moving between objects. (grade 4)**

This is a nice, grade-appropriate introduction to the zeroth law of thermodynamics.

Other concepts are well stated through the classroom applications document, such as:

> **Christina has two identical cups that are filled to the same level with water. She also has two solid steel balls.**
>
> - **Christina puts ball 1 in cup 1 and ball 2 in cup 2. In which cup will the water level rise the most? Tell why you think so.**
> - **Christina has another ball that is the same size as ball 2, but this ball is made of wood and is hollow. If she put this hollow ball in one of the cups, do you think the water level would rise more or less than it would if ball 2 were put in the cup?**
> - **Tell why you think so. (grade 6)**

Such classroom examples are helpful; the experiment is clearly described and readily performed, and the questions will make sixth graders think.

Unfortunately, many of the classroom examples are poorly written. For example, a fourth-grade chemistry standard asks students to "identify objects that are composed of a single substance and those that are composed of more than one substance using simple tools found in the classroom." In an illustrative experiment in the ancillary document, students are asked to conduct an experiment in which a graduated cylinder containing 60ml of salt water is left undisturbed for two days, after which the water is all gone and the cylinder contains a layer of salt. Of course, if the standards writers had actually conducted this experiment themselves, they would realize that, unless the cylinder is "left undisturbed" on a hot plate, most of the liquid will still be present.

New Jersey has no standards for high school physics or chemistry. Instead, the learning-progressions document includes a column labeled "by the end of grade 12" which, over the course of twelve pages, evenly covers chemical and physical subject matter. But the order is chaotic and the level mostly too low to furnish a basis for traditional high school chemistry or physics courses. Further, there is often poor progression between the document's content statements and CPIs—or no connection at all. For example, one content statement reads:

> **The conservation of atoms in chemical reactions leads to the ability to calculate the mass of products and reactants using the mole concept. (grade 12)**

While the corresponding CPI says only:

> **Balance chemical equations by applying the law of conservation of mass. (grade 12)**

Notice that both the term "mole concept" and any reference to stoichiometry found in the content statement are missing from the CPI. In fact the word "mole" only appears once in the whole document, in the example above. Overall, the high school material would be better suited for an eighth-grade physical science course.

Earth and Space Science

From Kindergarten on, the New Jersey earth and space science standards cover a good deal of critical content. For example, several topics from high school astronomy and cosmology are well explained, including theories about the origin of the universe and the solar system and stellar evolution, illustrated by the Hertzsprung-Russell diagram.

The structure and evolution of the Earth are also presented, with dating techniques and plate tectonics mentioned, though not always in enough detail. For example, by the end of eighth grade, students are asked to supply evidence for plate tectonic theory, but the standards give no indication of what that evidence is.

The rock cycle is covered reasonably well with the following sixth-grade standard:

> **The rock cycle is a model of creation and transformation of rocks from one form (sedimentary, igneous, or metamorphic) to another. Rock families are determined by the origin and transformations of the rock.**
>
> - **Distinguish physical properties of sedimentary, igneous, or metamorphic rocks and explain how one kind of rock could eventually become a different kind of rock. (grade 6)**

Unfortunately, as is the case in other disciplines, coverage of important content is sometimes superficial. In high school, for example, students are asked to:

> **Analyze the vertical structure of Earth's atmosphere, and account for the global, regional, and local variations of these characteristics and their impact on life. (grade 12)**

Not only is this demand excessively broad, the verb "analyze" is grandiose in this context.

The classroom applications documents often offer useful information to supplement the standards; however, they include a large number of links to external websites, which are relevant for a time but may quickly become outdated and unhelpful.

Life Science

The New Jersey life science standards sacrifice content for process. As a consequence, general concepts are presented with good logical flow but few details. And, even when details are given, concerns arise. For example, at the end of eighth grade, students are asked to:

> **Describe the environmental conditions or factors that may lead to a change in a cell's genetic information or to an organism's development, and how these changes are passed on. (grade 8)**

In fact, at this point there is no indication that students know how a cell's genetic information is encoded, and hence there is no way they can know how it changes. Moreover, changes in an organism's development, if not the consequence of genetic changes, are not "passed on."

Furthermore, the classroom examples that are added to clarify the standards range from hokey and inane to irrelevant and unrealistic. As an example of "hokey," one second-grade example shows a picture of four fish, one with long whiskers, and states, "Catfish have whisker-like parts around their mouths…" It then asks, "Which of these is a catfish?"

And one of "irrelevant and unrealistic":

> **You are the leader (mayor, principal, manager, etc.) of a human-created system (a city, a school, a restaurant, etc.). Compare, using an original metaphor, the functions and interdependence of cell organelles to the elements of your human-created system. Create a commercial to advertise your city, school, restaurant, etc. using the details of the organelles' functions to draw people in, highlighting how efficiently the elements work together, just like within a cell. (grade 6)**

What does this teach about organelles—or anything else for that matter?

The one saving grace in the life sciences is the high school treatment of evolution, which is quite comprehensive.

Given their serious shortcomings—magnified by the issues in the classroom-applications document—New Jersey's standards earn a woeful two out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

While the standards are clearly organized and presented, the expectations are often empty or jargon-filled. For instance, by the end of fourth grade, students are expected to:

> **Demonstrate understanding of the interrelationships among fundamental concepts in the physical, life, and Earth systems sciences. (grade 4)**
>
> **Use outcomes of investigations to build and refine questions, models, and explanations. (grade 4)**

These standards contain virtually no content; it's impossible to determine what students should know or be able to do.

Furthermore, standards are frequently repeated from grade to grade, offering no clear progression of content or rigor. Take, for example, the following:

> **Use mathematical, physical, and computational tools to build conceptual-based models and to pose theories. (grade 8)**
>
> **Develop and use mathematical, physical, and computational tools to build evidence-based models and to pose theories. (grade 12)**

Taken together, these drawbacks earn New Jersey a one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

New Mexico

GRADE	SCORES		TOTAL SCORE
C	Content and Rigor	4/7	6/10
	Clarity and Specificity	2/3	

REPORT CARD

Content & Rigor	**3.5**
Scientific Inquiry & Methodology	5
Physical Science	4
Physics	0
Chemistry	0
Earth & Space Science	5
Life Science	7
Clarity & Specificity	**1.5**

Average numerical evaluations

Document(s) Reviewed[1]

- *New Mexico Science Standards.* 2003, reformatted 2008. Accessed from: http://www.ped.state.nm.us/mathscience/scienceStandards.html

Overview

The New Mexico science standards start on the right track, but falter along the way. The standards are clear but lack adequate specificity. While the content that is presented is strong, the Land of Enchantment omits much necessary content. New Mexico's biggest flaw is a regrettable avoidance of quantitative methods.

Organization of the Standards

The K-12 New Mexico science standards are divided into three strands: scientific thinking and practice, content of science, and science and society. Each strand is then divided into a series of sub-strands, called standards. For instance, the three "standards" for the "content of science" strand are physical science, life science, and space science. Next, the state provides benchmarks for each of three grade bands (K-4, 5-8, and 9-12). Finally, grade-specific performance standards articulate how students will demonstrate mastery of each benchmark at each grade, K-8, and for the 9-12 grade band.

Content and Rigor

The operative words that describe the New Mexico science standards are "as far as they go" (which is somewhat ironic given the state's motto, *Crescit eundo*, or "it grows as it goes"). Overall, the standards are strong enough—as far as they go. And when they go far, as in life science, they are outstanding, covering all the necessary content with adequate depth and rigor. Alas, too often they fall short of that benchmark, particularly in upper level physical science, leaving their development in varying stages of completion. The result is an average performance that, with a little more effort, could have been excellent.

Scientific Inquiry and Methodology

While New Mexico's grade-specific performance standards for scientific inquiry and methodology are generally thorough, clear, and grade appropriate, the grade-band benchmarks add little value. Many are vague; for instance, from Kindergarten through fourth grade, students are asked to "use scientific methods to observe, collect, record, analyze, predict, interpret, and determine reasonableness of data." What makes data "reasonable" is anyone's guess.

[1] Fordham's 2005 evaluation also reviewed New Mexico's 2003 content-standards document. In 2008, the content standards were reformatted, changing the document some. In addition, the evaluation criteria used to judge the standards have been updated and improved since 2005. (See Appendix A for a complete explanation of criteria used in this review.) Through this new lens, and with this reformatted standards document, New Mexico's science grade dropped from an A to a C. The complete 2005 review can be found here: http://www.edexcellence.net/publications-issues/publications/sosscience05.html.

In addition, the benchmarks rarely make meaningful distinctions in content or rigor across grade bands. In fifth through eighth grades, one benchmark simply asks students to "use scientific methods to develop questions, design and conduct experiments using appropriate technologies, analyze and evaluate results, make predictions, and communicate findings." By high school, students are asked to "use *accepted* scientific methods to develop questions, design and conduct experiments using appropriate technologies, analyze and evaluate results, make predictions, and communicate findings" (emphasis added). As if using unacceptable methods were sufficient before high school.

In addition, the standards make no mention of the historical and social aspects of science.

Physical Science/High School Physics/High School Chemistry

Overall, New Mexico presents rigorous material for the elementary grades. Forms and states of matter are presented early—including the gas state, which is usually not covered until later:

> **Observe that the three states of matter (i.e., solids, liquids, and gases) have different properties (e.g., water can be liquid, ice, or steam).**
>
> **Describe simple properties of matter (e.g., hardness, flexibility, transparency). (grade 1)**

Other topics, including light, gravity, and forms of energy (kinetic, potential, and chemical) are equally well handled. Even better, atoms are first presented in fourth grade, with protons, neutrons, and electrons entering the standards in eighth grade.

Unfortunately, the New Mexico standards do stumble in their physical science expectations. While the necessary content is often present, some standards suffer from a lack of depth and completeness. Worse still, some standards are simply wrong, as in the following eighth-grade example:

> **Explain that elements are organized in the periodic table according to their properties. (grade 8)**

The state of the high school physical science standards is far worse. New Mexico fails to outline high school courses for either physics or chemistry, and important topics normally found in these courses are glossed over or missing entirely in the high school physical science standards. Indeed, all of high school physical science is shoehorned into about three-and-a-half pages. To be fair, what is present therein is generally well organized and well written, but at a level that cannot serve well as the basis for college-prep courses.

A particular concern is the virtual absence of mathematical relationships (including metric measurements). In spite of the piety of the high school benchmark asking students to "use mathematical concepts, principles, and expressions to analyze data, develop models, understand patterns and relationships, evaluate findings, and draw conclusions" (grades 9-12), $F = ma$ is about the only equation in the entire document. Newton's law of gravitation—the dependence of the gravitational force on the mass of two objects and the distance between them—is stated only qualitatively. No quantitative expression appears for the electrostatic force between two charges, either.

Worse still, some of the content included in the high school physical science standards is not rigorous enough even for a ninth-grade physical science course. For instance, there is no reason that students cannot be given an initial introduction to heat transfer mechanisms before high school. Yet, the first such introduction comes with the following high school standard:

> **Understand how heat can be transferred by conduction, convection, and radiation, and how heat conduction differs in conductors and insulators. (grades 9-12)**

On the chemistry side, a paucity of content likewise prevails. For instance, there are no standards about atomic models nor any mention of metallic or hydrogen bonding. The mole concept is not addressed, nor is molar volume (because ideal gases are not considered) or molarity (because the standards offer nothing on solutions). Spectra and electron transitions are only hinted at in the cryptic phrases "wavelengths of electromagnetic radiation" and "gain or lose energy only in discrete amounts."

In sum, while the physical science standards start off strong in the early grades, they degenerate dramatically in the later ones, leaving the deeper requirements of college-prep chemistry and physics courses unmet.

Earth and Space Science

The earth and space science standards for Kindergarten through eighth grade cover much essential content at an appropriate level of depth and with few errors. The coverage of space science is a little stronger than is that for solid earth material such as rocks and minerals, plate tectonics, and earthquakes.

For instance, there is an excellent sixth-grade standard that addresses the solar system:

> **Locate the solar system in the Milky Way galaxy.**

> **Identify the components of the solar system, and describe their defining characteristics and motions in space, including:**
>
> - **sun as a medium sized star**
> - **sun's composition (i.e., hydrogen, helium) and energy production**
> - **nine planets, their moons, asteroids. (grade 6)[1]**

On the earth science side, coverage is reasonable, but not outstanding. Often the trouble is that topics are merely mentioned, without explanatory details:

> **Know that Earth is composed of layers that include a crust, mantle, and core. (grade 6)**

Here, the layers are named but not described. What should students know about, for instance, the mantle? Then in high school:

> **Explain plate tectonic theory and understand the evidence that supports it. (grades 9-12)**

There is no way to judge the breadth or depth of such a standard.

> **Even with this occasional lack of detail, the New Mexico earth and space science standards are clear and businesslike, and cover most of the necessary territory with few obvious errors. They even present the occasional "wow" moment, as in this standard, beautifully accurate for Kindergarten: Observe that the sun warms the land and water and they warm the air. (Kindergarten)**

Likewise, the treatment of geologic time in high school is complete and rigorous:

> **Understand the changes in Earth's past and the investigative methods used to determine geologic time, including:**
>
> - **rock sequences, relative dating, fossil correlation, and radiometric dating**
> - **geologic time scales, historic changes in life forms, and the evidence for absolute ages (e.g., radiometric methods, tree rings, paleomagnetism). (grades 9-12)**

Life Science

The life science standards are generally clear, rigorous, and thorough. Students in second grade learn about the circulatory, digestive, and respiratory systems. Cells are introduced in fourth grade, and a seventh-grade unit on evolution is as good as or better than what is commonly seen in high school.

At the high school level, again there is excellent content on diversity, deep time, and common ancestry—with many fantastic standards covering important content at the appropriate depth. For instance, high school students are asked to:

> **Explain how cells differentiate and specialize during the growth of an organism, including:**
>
> - **differentiation, regulated through the selected expression of different genes**
> - **specialized cells, response to stimuli (e.g., nerve cells, sense organs). (grades 9-12)**

Biochemistry and cell biology are also well covered in high school. And, while there is little physiology at this level, the solid coverage of physiology in the standards for Kindergarten through eighth grade provides some consolation.

Further, the standards are pointedly accurate—not falling victim to the inaccuracies common in other states. For instance, eighth graders are commendably asked to "understand that all living organisms are composed of cells from one to many trillions." This is the right order of magnitude for such a statement; too many states inappropriately cap the number of cells at "millions."

There are, unfortunately, some statements that promulgate misconception. For instance, second-grade students are told to "know that bacteria and viruses are germs," when it would be better to "know that what are called 'germs' include bacteria and viruses."

Overall, New Mexico earns an average score of four out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The New Mexico science standards are straightforward and well written. However, the document reads a bit too much like an executive summary than a useful outline of an educational initiative, with lists of important terms included in a patchwork of examples alongside the performance standards.

A result is that critical details get lost in the compression. In physical science, for example, all of kinetic theory is contained in the single statement: "Explain how thermal energy (heat) consists of the random motion and vibrations of atoms and molecules and is measured by temperature" (grades 9-12).

[1] Note: This standard was written in 2003, before Pluto was demoted.

Similarly, for earth and space science, much content has been so condensed that it appears as a mere list of topics, without any indicator of depth or complexity:

> **Know that the regular and predictable motions of the Earth-moon-sun system explain phenomena on Earth, including:**
>
> - **Earth's motion in relation to a year, a day, the seasons, the phases of the moon, eclipses, tides, and shadows. (grade 6)**

And in chemistry, the words acidic, basic, neutral, pH, neutralization, and redox appear as terms in lists, but there is no real explanation or application made of them.

Of the two components to this category, New Mexico aces clarity but does not go nearly far enough in providing an adequate level of specificity. As such, the Land of Enchantment scores a two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

New York

GRADE	SCORES		TOTAL SCORE
B+	Content and Rigor	6/7	8/10
	Clarity and Specificity	2/3	

REPORT CARD

Content & Rigor	**5.7**
Scientific Inquiry & Methodology	2
Physical Science	4
Physics	7
Chemistry	7
Earth & Space Science	7
Life Science	7
Clarity & Specificity	**2.0**

Average numerical evaluations

Overview

New York's standards remain rigorous and thoughtfully composed. There are but a few weaknesses, principally in the handling of scientific inquiry; the overall quality is laudable.

Organization of the Standards

New York's learning standards for math, science, and technology are divided into seven strands, called "standards." Specifically for science, Standard 1 speaks to scientific inquiry and Standard 4 deals with science content. (Standards 6 and 7 discuss science themes and process skills, especially in connection with math and technology.) This analysis concentrates on Standards 1 and 4.

The content standards for science are divided into two sub-strands: physical setting and living environment. A series of "key ideas" are provided for each sub-strand. Finally, grade-span expectations are provided for each key idea at three levels: elementary (grades K-4), intermediate (grades 5-8), and commencement.

In addition, New York provides a *Core Curriculum* (optional, though dealing specifically with state-tested content), which lists a series of "major understandings" for each of the grade-span expectations. For instance, an elementary expectation asks students to "describe the characteristics of and variations between living and nonliving things." The four major understandings spell out precisely what characteristics and variations are intended at this level:

- **1.1a Animals need air, water, and food in order to live and thrive.**
- **1.1b Plants require air, water, nutrients, and light in order to live and thrive.**
- **1.1c Nonliving things do not live and thrive.**
- **1.1d Nonliving things can be human-created or naturally occurring. (elementary grades)**

This is straightforward, clear, and grade-appropriate exposition.

Content and Rigor

New York's standards are generally outstanding, with excellent content in both the lower and upper levels in most disciplines.

Document(s) Reviewed

- *New York Learning Standards and Core Curriculum (Standards 1 and 4)*. 1996. Accessed from: http://www.p12.nysed.gov/ciai/mst/sci/sciencestand/scistand.html
- *Resource Guide with Core Curriculum*. May 2009. Accessed from: http://www.p12.nysed.gov/ciai/mst/sci/ls.html

Scientific Inquiry and Methodology

The scientific inquiry and methodology standards are perhaps the biggest blight on an otherwise strong set of student expectations. Not only are the inquiry standards awkwardly linked with "mathematical analysis" and "engineering design" standards, they are rife with platitudes, such as: "Students learn most effectively when they have a central role in the discovery process." New York's inquiry standards do not provide clear direction as to their application in the classroom. For example, elementary students are expected to "make informed decisions and solve problems" using interdisciplinary problem solving. Fair enough. But how? Further, there is no indication of how the various grades would achieve this goal in a progressive manner. The standards are further weakened by the overuse of jargon such as "cost/benefit trade-offs," "optimal choice," and "fair test." For instance, at the elementary level students are asked to:

> **Observe phenomena and evaluate them scientifically and mathematically by conducting a fair test of the effect of variables and using mathematical knowledge and technological tools to collect, analyze, and present data and conclusions. (elementary grades)**

There is virtually no content in this bloated and jargon-filled standard. Sadly, these are the norm, rather than the exception.

Physical Science

Relative to the strong coverage of other disciplines, elementary- and intermediate-level physical science is a weak spot for the New York standards. Too much critical content is omitted, particularly in elementary grades, when students should be learning critical prerequisite content that will lay the groundwork for later learning.

The standards do improve in depth and rigor as they progress through the grade levels—though weaknesses still occasionally emerge, even in the intermediate grades. The word "molecule" is frequently used, for example, but is never defined. And some standards misrepresent aspects of physical science altogether. The following is illustrative:

> **Energy can be transformed, one form to another. These transformations produce heat energy. Heat is a calculated value which includes the temperature of the material, the mass of the material, and the type of the material. (intermediate grades)**

Close, but no cigar. Heat energy is not necessarily involved in energy transformations. Heat is a mode of transfer of energy, not a fixed quantity of energy.

High School Physics

High school physics is covered in a complete and systematic way. The treatment begins with a step-by-step exposition of energy, beginning with:

> **All energy transfers are governed by the law of conservation of energy.***
>
> **Energy may be converted among mechanical, electromagnetic, nuclear, and thermal forms.**
>
> **Potential energy is the energy an object possesses by virtue of its position or condition. Types of potential energy include gravitational* and elastic*.**
>
> **Kinetic energy* is the energy an object possesses by virtue of its motion.**
>
> **In an ideal mechanical system, the sum of the macroscopic kinetic and potential energies (mechanical energy) is constant.* (high school physics)**

And generalizing to such matters as:

> **Energy may be stored in electric* or magnetic fields. This energy may be transferred through conductors or space and may be converted to other forms of energy.**
>
> **Moving electric charges produce magnetic fields. The relative motion between a conductor and a magnetic field may produce a potential difference in the conductor.**
>
> **Electrical power* and energy* can be determined for electric circuits. (high school physics)**

Here and elsewhere, the asterisks mark concepts and topics for which quantitative treatment is required—showing that the state requires a pretty thorough quantitative approach to the study of physics, something often lacking in states' standards.

Following the coverage of energy is, quite logically, the coverage of waves, kinematics and dynamics, and quantum physics. The treatment of this last broad topic is perhaps too brief, but this is largely compensated for by excellent coverage in high school chemistry both of thermodynamics and of atomic structure and interactions (more on this topic below). The relative brevity of treatment does not interfere with completeness, owing to the careful and knowledgeable organization of the subject matter.

High School Chemistry

The New York chemistry standards outline a solid, academic, college-prep high school chemistry course—the standards are truly a pleasure to read. Open the document to any page and you will find carefully crafted statements that are wonderfully specific, clearly telling the reader what students are expected to know and be able to do. Scientific terms are defined and the word "calculate" appears without shame when mathematical relationships are presented. To sample a flavor of the whole, consider these definitions of heat and temperature, so often slighted or muddled in state science standards:

> **Heat is a transfer of energy (usually thermal energy) from a body of higher temperature to a body of lower temperature. Thermal energy is the energy associated with the random motion of atoms and molecules.**
>
> **Temperature is a measurement of the average kinetic energy of the particles in a sample of material. Temperature is not a form of energy. (high school chemistry)**

This is correct, clear, and complete; not a word is wasted. From the outset, it is made clear that heat is not energy *per se* but a mode of energy transfer; the distinction is well made between heat and thermal energy.

Similarly, the dynamic nature of chemical equilibrium is set forth clearly in three standards:

> **Some chemical and physical changes can reach equilibrium.**
>
> **At equilibrium the rate of the forward reaction equals the rate of the reverse reaction. The measurable quantities of reactants and products remain constant at equilibrium.**
>
> **Le Châtelier's Principle can be used to predict the effect of stress (change in pressure, volume, concentration, and temperature) on a system at equilibrium. (high school chemistry)**

This is followed immediately by a straightforward presentation of Le Châtelier's principle.

Redox reactions and acid-base chemistry are also thoroughly covered, as are all the other key elements of a rigorous high school chemistry curriculum.

Earth and Space Science

Though there are a few black marks within New York's earth and space science standards (too much peripheral material sometimes detracts from the content, for example), the Empire State's standards in this discipline represent some of the best in the nation. The use of strong examples that clarify what, precisely, students should know or be able to do differentiate New York's standards from the rest. For example, the following three expectations appear in high school:

> **Minerals are formed inorganically by the process of crystallization as a result of specific environmental conditions. These include:**
>
> - **cooling and solidification of magma**
> - **precipitation from water caused by such processes as evaporation, chemical reactions, and temperature changes**
> - **rearrangement of atoms in existing minerals subjected to conditions of high temperature and pressure. (high school earth science)**
>
> **Age relationships among bodies of rocks can be determined using principles of original horizontality, superposition, inclusions, cross-cutting relationships, contact metamorphism, and unconformities. The presence of volcanic ash layers, index fossils, and meteoritic debris can provide additional information. (high school earth science)**
>
> **The regular rate of nuclear decay (half-life time period) of radioactive isotopes allows geologists to determine the absolute age of materials found in some rocks. (high school earth science)**

These examples, drawn from the *Core Curriculum*, leave little doubt as to what students should learn. But while the *Curriculum* clearly delineates what is expected of students, it suffers from one weakness: some important elementary content is delayed until high school.

Life Science

The elementary and intermediate life science standards are thorough and rigorous. Virtually all of the content is well presented and developed, and the section on human organ systems is particularly impressive.

The high school standards are also excellent throughout. In particular, the standards covering the integration of systems with disease and the way genetics is intertwined with embryological development and evolution are noteworthy.

Evolution is well covered. One quibble is that the high school document states: "According to many scientists, biological evolution occurs through natural selection." Because the document goes on to indicate that natural selection is key, and describes it well, we have reason to hope that the "according to many scientists" part—so dear to creationists—will vanish in the next rewrite.

With the exception of its treatment of inquiry and elementary-level physical science, the New York standards are clear, thorough, and rigorous. They earn an admirable average score of six out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

New York's *Core Curriculum*, designed to build on the state's learning standards, contains some of the most elegant writing of any science standards document. Take, for example, the following two high school earth science standards:

> **The universe is vast and estimated to be over ten billion years old. The current theory is that the universe was created from an explosion called the Big Bang. Evidence for this theory includes:**
>
> - **cosmic background radiation**
> - **a red-shift (the Doppler effect) in the light from very distant galaxies. (high school earth science)**

> **Patterns of deposition result from a loss of energy within the transporting system and are influenced by the size, shape, and density of the transported particles. Sediment deposits may be sorted or unsorted. (high school earth science)**

Such clear exposition of accurate scientific material is typical of the *Core Curriculum*.

Unfortunately, the eloquence of that document is mitigated by the organization of the learning standards themselves, which are convoluted and confusing. Though not impossible, navigating these—the official standards—can be quite the headache. The poor organization of the learning standards lowers New York's clarity and specificity score to a two out of three. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

North Carolina

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	3/7	4/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**2.7**
Scientific Inquiry & Methodology	0
Physical Science	4
Physics	2
Chemistry	4
Earth & Space Science	2
Life Science	4
Clarity & Specificity	**1.4**

Average numerical evaluations

Overview

Despite promise in some areas, the North Carolina science standards cannot overcome several serious flaws. Chief among them is a general lack of detail that compromises the standards' utility as an educational framework. Even when specific content is present, it often is poorly developed, confusing, or misleading. The authors of the standards appear to have disregarded North Carolina's state motto of "esse quam videri"—"to be, rather than to seem"—when writing the material.

Organization of the Standards

North Carolina's science standards are presented through a series of documents, one for each grade, K-8, and for individual high school courses in physical science, biology, chemistry, physics, and earth/environmental. The state also presents a series of Advanced Placement course documents. Within each document, standards are presented first by strand. They are then broken down by "competency goal" and finally by "clarifying objectives." A "science as inquiry" section frames standards at each grade and discipline.

Content and Rigor

The North Carolina standards are crippled by their overemphasis on generality at the expense of concrete examples. And with so few details, the occasional gross errors and confusing statements stand out all the more starkly. The material does have strong moments: For example, the early grades in physical science and chemistry, as well as the life science section, have merit. But overall, the outcome is poor, and there is no reason to hope that a solid curriculum could emerge from the mess.

Scientific Inquiry and Methodology

The preamble to the process portion of the standards mentions "scientific inquiry" a total of four times, yet in no place in the standards does inquiry receive careful attention, and the promised "seamless integration" of science content and scientific inquiry is nowhere to be seen. What exists is a paragraph offering bromides (such as "research shows that young students work well in a cooperative learning environment") but little direction as to how concepts such as theory, hypothesis, and law are to be introduced or integrated with the content. While, as the high

Document(s) Reviewed

- *North Carolina Essential Learning Standards: Science*. 2009. Accessed from: http://www.ncpublicschools.org/acre/standards/new-standards/#science school standards tell us, “student engagement in scientific investigation provides background for understanding the nature of scientific inquiry,” this document offers little guidance as to how to incorporate inquiry in the classroom.

Physical Science

The physical science standards are reasonably thorough and rigorous in the early grades. Take, for example, the following introduction to mass conservation and phase changes:

> **Compare the amount (volume and weight) of water in a container before and after freezing. (grade 2)**

Similarly, the third-grade standards introduce the zeroth law of thermodynamics clearly and in a way that’s entirely grade appropriate:

> **Recognize that energy can be transferred from a warmer object to a cooler one by contact or at a distance and the cooler object gets warmer. (grade 3)**

There is a sound introduction to the concept of energy in fourth grade:

> **Recognize the basic forms of energy (light, sound, heat, electrical, and magnetic) as the ability to cause motion or create change. (grade 4)**

The standards are also well-linked to other scientific disciplines in the early grades. Two examples, from second and fifth grades, respectively, are the following:

> **Understand the relationship between sound and vibrating objects.**
>
> - **Illustrate how sound is produced by vibrating objects and columns of air.**
> - **Summarize the relationship between sound and objects of the body that vibrate—eardrum and vocal cords. (grade 2)**
>
> **Explain how the sun’s energy impacts the processes of the water cycle (including, evaporation, transpiration, condensation, precipitation, and runoff). (grade 5)**

Unfortunately, the coverage of important content becomes increasingly sketchy as the grades progress. By sixth grade and on through eighth grade the presentation is disorganized, illogically sequenced, and riddled with misconceptions and mistakes. For instance, the statement in sixth grade that matter is made of atoms is all the standards have to say on the subject. Similarly, only one sixth-grade standard—“explain the effect of heat on the motion of atoms through a description of what happens to particles during a change in phase”—lays out expectations for what students should learn about the connection between heat energy and molecular motion.

Further, the standards often present material inappropriate for the grade level in which it is introduced. Take, for example, the following fifth-grade standard:

> **Explain how factors such as gravity, friction, and change in mass affect the motion of objects. (grade 5)**

Change in mass? Why would one want to introduce the dynamics of bodies of non-constant mass in fifth grade? One suspects that what was really intended is the dependence of acceleration on the mass of the object to which a force is applied.

Similarly, the following high school physical science standard is a decidedly mixed bag, presenting kinematics, momentum, unspecified “investigations,” and mathematical quantities all in one opaque mess:

> **Compare speed, velocity, acceleration, and momentum using investigations, graphing, scalar quantities, and vector quantities. (high school physical science)**

Sadly, these examples are but a few of many.

High School Physics

Most of the essential content is missing from the North Carolina high school physics standards—an unsurprising consequence, given that the standards barely fill two pages. What is presented varies in quality. After an excellent treatment of mechanics, a good start to electromagnetism descends into chaos. To give one example of this decline, consider the following standard and one of its clarifying objectives:

> **Analyze the nature of moving charges and electric circuits.**
>
> - **Explain Ohm’s law in relation to electric circuits. (high school physics)**

But Ohm’s law is a property of a class of circuit components (called ohmic or resistive elements) and the last five words of the sentence only confuse.

In another standard, students are asked to “differentiate the behavior of moving charges in conductors and insulators.” Unfortunately, insulators are objects in which electric charge does not move. Another standard asks students to “compare the general characteristics of AC and DC systems without calculations.” What that means in practice is anyone’s guess.

Again, these examples are but a few of many. And then the document screeches to a halt. There is nothing at all about light, sound (other than a very brief mention of waves in general), atomic or nuclear physics, or relativity.

High School Chemistry

Like physics, all of high school chemistry is outlined in only thirty-one clarifying objectives, spread out in a two-page table that renders the list of topics addressed incomplete. Missing topics include: hydrogen bonding, Lewis dot structures, molecular shape and polarity, the mole concept, oxidation/reduction, and carbon chemistry. Content that is included is frequently hidden in terse statements that are hopelessly general, as in:

> **Analyze the structure of atoms, isotopes, and ions. (high school chemistry)**

> **Analyze the stoichiometric relationships inherent in a chemical reaction. (high school chemistry)**

These objectives leave the reader guessing what the writer had in mind. To most chemistry teachers, "stoichiometric relationships" in the second example implies mole ratios, but the mole concept is not mentioned. For that, we must turn to another standard, which merely hints at it: "Infer the quantitative nature of a solution (molarity, dilution, and titration with a 1:1 molar ratio)" (high school chemistry).

Still, while most standards miss the mark, a few take more careful aim and address content adequately:

> **Compare the properties of ionic, covalent, metallic, and network compounds.**

> **Analyze quantitatively the composition of a substance (empirical formula, molecular formula, percent composition, and hydrates).**

> **Interpret the name and formula of compounds using IUPAC convention. (high school chemistry)**

Also, concepts of equilibrium and periodic table relationships are well covered.

Earth and Space Science

Earth science, astronomy, and environmental science are presented as a single subject—and cover a mere two pages. Given this lack of real estate, the North Carolina earth and space science standards often cram too much content into individual standards—especially at the high school level, as in the following example:

> **Explain the Earth's motion through space, including precession, nutation, the barycenter, and its path about the galaxy. (high school earth/environmental)**

> **Explain how the rock cycle, plate tectonics, volcanoes, and earthquakes impact the lithosphere. (high school earth/environmental)**

That's a lot of complex content to ask in less than twenty words each—one is reminded of Monty Python's "Summarize Proust In Thirty Seconds" routine. The brevity of the standards also can lead to confusion and oversimplification of ideas, as in the following:

> **Explain how crustal plates and ocean basins are formed, move, and interact using earthquakes, heat flow, and volcanoes to reflect forces within the earth. (grade 6)**

> **Explain how the Earth's rotation and revolution about the Sun affect its shape and is [*sic*] related to seasons and tides. (high school earth/environmental)**

In the case of the latter, the slight nonsphericity of the earth is indeed due to its rotation, but the importance of that effect hardly merits its grouping with seasons, while rotation alone does not account for the tides.

Often there are vast blanks where content is missing. At the high school level, there is nothing at all about extra-solar-system astronomy or cosmology, and coverage of plate tectonics is thin throughout.

Still, a search for our suggested content turned up a few nicely crafted statements. Fourth grade contains:

> **Explain how minerals are identified using tests for the physical properties of hardness, color, luster, cleavage, and streak. (grade 4)**

> **Classify rocks as metamorphic, sedimentary, or igneous based on their composition, how they are formed, and the processes that create them. (grade 4)**

Both of these are specific and appropriately rigorous, if a little too narrow in scope. The first could be improved by mentioning special properties such as magnetism and reaction to acid. The second could be improved by calling out the recycling of materials during those processes—how they form a rock cycle.

Life Science

The life science standards are equally brief—and the content coverage suffers here as elsewhere. Evolution is not introduced until eighth grade, and then it begins with this:

> **Understand the evolution of organisms and landforms based on evidence, theories, and processes that impact the Earth over time. (grade 8)**

All of biological and geological evolution in a single sentence! And then a single additional bit:

> **Summarize the use of evidence drawn from geology, fossils, and comparative anatomy to form the basis for biological classification systems and the theory of evolution. (grade 8)**

But there is no mention of natural selection, variation, and so forth.

High school biology also suffers from some glaring omissions, including organ systems and physiology. Still, for the most part, the subjects that are mentioned are sound, though their generality may confound teacher and student. Examples are as follows:

> **Explain how instructions in DNA lead to cell differentiation and result in cells specialized to perform specific functions in multicellular organisms.**
>
> **Explain how DNA and RNA code for proteins and determine traits.**
>
> **Explain how fossil, biochemical, and anatomical evidence support the theory of evolution. (high school biology)**

Perhaps a skilled educator could cobble together an effective curriculum from the North Carolina standards. But doing so would require an uncanny ability to imagine material that's missing from the document. With so many blank spots, the overall average score for content and rigor is just three out of seven. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

Although reasonably well ordered and written in grammatical prose, the standards are far too vague to guide curriculum, instruction, or assessment development. Take, for example, this fifth-grade life science standard:

> **Explain why organisms are different from or similar to their parents based on the characteristics of the organism. (grade 5)**

This standard contains virtually no meaningful content or guidance. And sadly, such an example is the norm, not the exception. And there are some incomprehensible standards, such as:

> **Explain ways that organisms use released energy for maintaining homeostasis (active transport). (high school biology)**

Puzzling statements like these undermine the already-thin text and result in an overall score of one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

North Dakota

GRADE	SCORES		TOTAL SCORE
F	Content and Rigor	1/7	1/10
	Clarity and Specificity	0/3	

REPORT CARD

Content & Rigor	**1.3**
Scientific Inquiry & Methodology	2
Physical Science	2
Physics	0
Chemistry	0
Earth & Space Science	3
Life Science	1
Clarity & Specificity	**0.3**

Average numerical evaluations

Overview

The North Dakota science standards contain nothing of scientific or pedagogical utility. They are, in essence, worthless, and could not possibly serve as the basis for supplying young Peace Gardeners with a proper science education.

Organization of the Standards

North Dakota's *Science Content and Achievement Standards* are divided into eight content standards: unifying concepts, science inquiry, physical science, life science, earth and space science, science and technology, science and other areas, and history and nature of science. Grade-specific benchmarks are then provided grade-by-grade in grades K-8, and by grade band for grades 9-10 and 11-12.

The state also supplies "proficiency descriptors" for each benchmark, though these do not add much to the benchmarks themselves. Instead, they state that students at each of four levels of proficiency—advanced proficient, proficient, partially proficient, and novice—will show comprehension that is "insightful," "reasonable," "superficial," or "unreasonable," respectively.

Content and Rigor

There is nothing good to say about the scientific content of the North Dakota standards. Indeed, there is little point in unfolding the scientific disciplines one by one, and we do not do so here. Instead, we review all content areas together to illustrate the significant problems that are found across disciplines.

Scientific Inquiry and Methodology

These standards appear to have changed little since our 2005 review (at which time only a draft version of the standards was available). They are still plagued by vagueness and a lack of guidance for teachers seeking to achieve the benchmark expectations in the classroom. Expectations are keyed to instructionally useless "proficiency descriptors." For example, the expectation that students in ninth and tenth grades "maintain clear and accurate records of scientific investigations" has descriptors that claim that "advanced proficient" students should "always" do so, while "novice" students "rarely" do. The time spent on generating these trivial descriptors would

Document(s) Reviewed

- *North Dakota Science Content and Achievement Standards*. 2006. Accessed from: http://www.dpi.state.nd.us/standard/content/science/index.shtm have been better spent in developing a fuller and clearer set of expectations. As we noted in 2005, an expectation that students "use appropriate tools and techniques" offers little guidance to the teacher—or for that matter, anyone else.

All Content Areas

Remarkably, not one of the thirty-three members of the content-standards writing team represented a university science department or came from the scientific or engineering community. The entire team consists of persons connected with K-12 schools and school districts. Two consultants, an evaluator, and two coordinators hailed from Mid-continent Research for Learning and Education and the state Department of Public Instruction. Among the twenty members of the achievement-standards writing team, we do find one botanist from a small college and a geologist from the state geological survey. (This last person may account for the relatively better presentation of earth science.)

This astonishing lack of real expertise in science shows in the empty—if bulky—documents. Throughout the physical science sections, for example, about three-quarters of the major subjects we would expect to be covered are missing. What is present is sketchy to the point of uselessness. For instance, here is all that is said about force and motion in eleventh and twelfth grades:

> **Identify the principles and relationships influencing forces and motion (e.g., gravitational force, vectors, velocity, friction). (grades 11-12)**

And at the same grade level, this is the sum total of the coverage of chemical equations:

> **Balance chemical equations. (grades 11-12)**

Sadly, such examples are the rule, not the exception. In seventh-grade life science, the only time either genetics or reproduction is even mentioned is in the following vague standard:

> **Identify the characteristics of reproduction (e.g., sexual, asexual). (grade 7)**

At the same level, two standards lay out all the state expects students to know about diversity and unity among organisms:

> **Classify organisms (e.g., taxonomic groups).**
>
> **Explain how different adaptations help organisms survive. (grade 7)**

A quick scan of any discipline at any grade level would turn up similarly useless standards. As such, North Dakota barely ekes out an average score of one out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The language is not muddled but the content is negligible; this unusable pair of documents earns a zero out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Ohio

GRADE	SCORES		TOTAL SCORE
B	Content and Rigor	5/7	7/10
	Clarity and Specificity	2/3	

REPORT CARD

Content & Rigor	**4.8**
Scientific Inquiry & Methodology	2
Physical Science	6
Physics	4
Chemistry	6
Earth & Space Science	6
Life Science	5
Clarity & Specificity	**1.8**

Average numerical evaluations

Document(s) Reviewed[1]

- *Ohio Revised Science Standards and Model Curriculum: Grades PreK through Eight*. 2011. Accessed from: http://www.ode.state.oh.us/GD/DocumentManagement/DocumentDownload.aspx?DocumentID=107333

- *Ohio Revised Science Standards and Model Curriculum: High School*. 2011. Accessed from: http://www.ode.state.oh.us/GD/DocumentManagement/DocumentDownload.aspx?DocumentID=105412

[1] In this review, we examine Ohio's recently adopted (2011) science standards. While these are now the state's official science standards, teachers are still directed to use the 2002 standards until assessments aligned with the 2011 standards are implemented "in several years." So while the 2011 standards examined here are not currently in use, this review will help guide Ohio when deciding whether to adopt the Next Generation Science Standards (see Introduction). A review of Ohio's 2002 standards can be found here: http://www.edexcellence.net/publications-issues/publications/sosscience05.html.

Overview

The documents that comprise the Ohio science standards are excessively long (four hundred pages), making it difficult to wade through the material to tease out the essential content. That said, educators with sufficient endurance will be able to find reasonably rigorous K-12 science content that can become a solid foundation for effective curricula, instruction, and assessment.

Organization of the Standards

The Ohio preK-8 science standards are divided into three strands: earth and space science, physical science, and life science. For each strand, a series of topics are then presented. For instance, topics within the earth and space science strand include "Earth's surface" and "cycles and patterns in the solar system." These are followed by grade-specific standards, called "content statements." For each content statement, the state provides a series of "content elaborations," which are several-paragraph descriptions of how the content statements relate to those of previous and later grades. The content elaborations also provide more detailed descriptions of what students should know about each topic.

Along with the content expectations, Ohio's standards and curriculum document is chockablock with additional material. For instance, each topic includes an inquiry-based "expectations for learning" section (apart from the inquiry standards themselves), a series of model classroom lessons, and advice on how to handle diverse learners.

Ohio's high school standards and curricula are organized similarly, though material is presented by course instead of grade for the following courses: introductory physical science, introductory biology, advanced chemistry, environmental science, physical geology, and physics.

Content and Rigor

The scientific content in the Ohio standards starts strong and, refreshingly, gains strength with advancing grade levels. Nuggets of excellent material emerge with increasing frequency through the middle school years and into high school (though a great deal of content is missing from high school physics). Generally, content statements are carefully written, scientifically accurate, and elegantly presented.

Scientific Inquiry and Methodology

The standards set forth brief goals, repeated across grades, for the state's "science inquiry and applications" section. There are six for pre-Kindergarten through fourth grade, eight for grades five through eight, and six for high school. Students are expected to become proficient in these as they "construct their knowledge and understanding in all science content areas." Ironically, given the verbosity of the rest of the material, the goals are often briefer than they ought to be. For example, between pre-Kindergarten and fourth grade, students will "plan and conduct simple investigations," but when one looks at the actual standards it is difficult to ascertain how this skill is to develop over the six-year period.

While it is important for states to embed their process and inquiry standards within their content standards, Ohio does this in such a way as to obscure what skills students should master. Worse, the related classroom examples (e.g., "plan and implement a scientific experiment" in fifth grade) add little value.

Similarly empty standards can be found at the high school level. For instance, a section called "visions into practice," mentions the history of science and directs students to "develop a timeline from Mendel's, Darwin's, and Wallace's work to the present day," but it's unclear *why* students should engage in such an exercise.

Physical Science

Physical science is presented in narrative form, rather than lists of content, and the result is a clear exposition of essential content (albeit with a few important topics missing, including the mole concept and the writing and balancing of chemical equations). For some reason, all mention of atoms, displacement, and velocity is deferred until high school, as is all quantitative work.

Physical concepts at the elementary levels are beautifully treated. In second grade, for example:

> **Forces are needed to change the movement (speed up, slow down, change direction or stop) of an object. Some forces may act when an object is in contact with another object (e.g., pushing or pulling). Other forces may act when objects are not in contact with each other (e.g., magnetic or gravitational). (grade 2)**

In fourth grade, a writer who clearly understands physics introduces the tricky concept of heat:

> **The word "heat" is used loosely in everyday language, yet it has a very specific scientific meaning. ... An object has thermal energy due to the random movement of the particles that make up the object. ... "Heating" is used to describe the transfer of thermal or radiant energy to another object or place. Differentiating between these concepts is inappropriate at this grade level. ... However, the word "heat" has been used with care so it refers to a *transfer* of thermal or radiant energy. (grade 4)**

This statement is correct, well crafted, and admirably rigorous for the grade level.

Further, the treatment of physical science in ninth grade offers a nice overview of Newtonian mechanics, quite reasonably limited to one-dimensional cases.

High School Physics

The coverage of some basic high school physics topics is clear and thorough. The course begins with a fine treatment of kinematics in one and two dimensions, based on a recapitulation of what the student already knows from the preceding physical science material. This is followed by detailed discussion of graphing (position, velocity, and acceleration as functions of time) and of motion in one and two dimensions, exemplified by free fall and projectile motion. A thorough treatment of dynamics logically follows, using Newton's laws to analyze Atwood's machines and applying them to gravitational, elastic, frictional, and hydrodynamic forces, with special attention to curvilinear motion.

Momentum and impulse are treated especially well, as is mechanical energy (though nuclear energy is rather incongruously introduced at this point).

A well-written section on waves and optics follows, and then a section on electromagnetism. There are fine treatments here of electrostatics and Coulomb's law, which is laudably and explicitly stated through its mathematical expression ($F_e = k_e q_1 q_2 / r^2$), ensuring that students know more than just the concept of the law, but how to apply it. This is followed by a discussion of electric fields and potentials, and some practical applications to electric circuits. However, electromagnetism is dealt with somewhat sketchily, with no mention of Ampère's or Faraday's laws.

Unfortunately, a great deal of important material is missing. Modern physics (with the exception of a brief citation of nuclear energy) is not covered at all; neither is thermal physics. In fact, a discussion of conservation of energy makes no mention of heat energy. Indeed, a search of the entire high school physics material reveals not a single use of the words "heat" or "thermal." Given that the subject was introduced at the lower physical science level, it is odd that it is slighted here.

High School Chemistry

Like the other high school courses, chemistry is presented as an outline followed by a series of fairly lengthy essays which cover the subject matter. Here is a typical example:

> **Properties of acids and bases and the ranges of the pH scale were introduced in middle school. In [high school] chemistry, the structural features of molecules are explored to further understand acids and bases. Acids often result when hydrogen is covalently bonded to an electronegative element and is easily dissociated from the rest of the molecule to bind with water to form a hydronium ion (H_3O^+). The acidity of an aqueous solution can be expressed as pH, where pH can be calculated from the concentration of the hydronium ion. Bases are likely to dissociate in water to form a hydroxide ion. Acids can react with bases to form a salt and water. Such neutralization reactions can be studied quantitatively by performing titration experiments. Detailed instruction about the equilibrium of acids and bases and the concept of Brønsted-Lowry and Lewis acids and bases will not be assessed at this level. (high school chemistry)**

Generally, this coverage is clear and complete, as well as carefully integrated into what students have already learned—with the exception that both the Brønsted-Lowry and Lewis definitions of acids and bases are explicitly excluded. It is disappointing to see such limits placed on student exploration. And, unfortunately, other important topics are similarly—and unnecessarily—limited.

This tendency to leave out reasonable high school chemistry content or, as in the example above, specifically omit it, weakens what otherwise would serve as superior standards.

Earth and Space Science

Earth and space science gets off to a typically slow start, with little substance in the primary grades. But once the standards pick up speed, there is much terrific material, as in the following:

> **The distance from the sun, size, composition and movement of each planet are unique. Planets revolve around the sun in elliptical orbits. Some of the planets have moons and/or debris that orbit them. Comets, asteroids and meteoroids orbit the sun. (grade 5)**

The treatment of minerals is also exceptional, as is that of earth-surface features in eighth grade. With that level of detail, however, small errors occasionally creep in, such as in the following:

> **Historical data and observations such as fossil distribution, paleomagnetism, continental drift and sea-floor spreading contributed to the theory of plate tectonics. The rigid tectonic plates move with the molten rock and magma beneath them in the upper mantle. (grade 8)**

Plates are made of lithosphere rather than crust, and for the most part the mantle is not molten.

Such flaws are minor, however, and are more than balanced by many praiseworthy entries. (Even the statement above has redeeming qualities—it touches on the evidence for plate-tectonic theory, for example, which many states ignore.)

The organization of the high school material is a bit quirky—though the quirks don't necessarily distract from strong coverage of important topics. The astronomy content usually found in earth and space science instead appears in the physical science course. But there, it is handled exceptionally well. The content elaboration for "stars" offers just one example of complete and helpful information:

> **Early in the formation of the universe, stars coalesced out of clouds of hydrogen and helium and clumped together by gravitational attraction into galaxies. When heated to a sufficiently high temperature by gravitational attraction, stars begin nuclear reactions, which convert matter to energy and fuse the lighter elements into heavier ones. These and other fusion processes in stars have led to the formation of all the other elements. (NAEP 2009). All of the elements, except for hydrogen and helium, originated from the nuclear fusion reactions of stars (College Board Standards for College Success, 2009). (high school physical science)**

Further, the high school physical geology material is elegant and ambitious, incorporating chemistry, physics, and environmental science—though sometimes just in keyword-outline form. Advanced topics with high explanatory value, such as isostasy, are presented.

Life Science

The Ohio life science standards are generally strong and include much essential content. Mendelian genetics, for example, is well treated in eighth grade and evolution receives strong coverage throughout. Fossils are covered in second, fourth, and eighth grades, and a major unit in high school readdresses the topic thoroughly, including common descent, deep time, and cladistics. Evolution is firmly grounded as the central concept of the life sciences:

> **Biological evolution explains the natural origins for the diversity of life. Emphasis shifts from thinking in terms of selection of individuals with a particular trait to changing proportions of a trait in populations. The study of evolution must include Modern Synthesis, the unification of genetics and evolution and historical perspectives of evolutionary theory. The study of evolution must include gene flow, mutation, speciation, natural selection, genetic drift, sexual selection and Hardy Weinberg's law [*sic*]. (high school biology)**

There is considerably more of this clear and detailed development of evolution standards. The mention of genetic drift—a rarity in state science standards—deserves particular mention. (The overall quality of the passage is such that we can forgive the writer who imagined that Hardy Weinberg was a single person and thus muddled the Hardy-Weinberg law.)

The largest omissions from the life science standards are of organ systems and physiology. Neither is covered at any grade level—a search of both the elementary and high school documents yields no reference to nerves, hormones, or digestion.

The content that Ohio does cover is strong across all subjects. However, key omissions, especially in high school physics and in life science, bring the Buckeye State's average content and rigor score down to a five out of seven. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The most significant shortcoming of the Ohio science standards is the sheer volume of the materials. Combining the standards with the model curriculum does not help.

Some of the supplementary material, however, does serve to clarify expectations. For instance, the state has added lists of common misconceptions, which will be of particular use to inexperienced teachers:

> **Although two materials are required for the dissolving process, children tend to focus only on the solid and they regard the process as melting…When things dissolve they disappear. Melting and dissolving are confused. (grade 1)**

However, one must wade through a great deal of boilerplate to find the useful material—a sometimes frustrating and always time-consuming experience. All in all, Ohio has produced a fine set of science standards nestled within a great deal of verbiage. Fortunately, the documents tend to be well written, if not precisely to the point. As such, Ohio earns a commendable two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Oklahoma

GRADE	SCORES		TOTAL SCORE
F	Content and Rigor	1/7	2/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**1.2**
Scientific Inquiry & Methodology	2
Physical Science	2
Physics	2
Chemistry	1
Earth & Space Science	0
Life Science	0
Clarity & Specificity	**0.6**

Average numerical evaluation

Document(s) Reviewed

- *Priority Academic Student Skills: Science.* March 2011. Accessed from: http://sde.state.ok.us/Curriculum/PASS/Subject/science.pdf

Overview

The Oklahoma science standards are simply not OK. Woefully little science content appears, and what is present is often flat out wrong, oddly worded, or not up to grade level. It is difficult to see how any curriculum that emerged from these standards (assuming that one could accomplish that task on such a basis) would not be fatally flawed. Oklahoma's motto is *Labor omnia vincit*—labor conquers all things—but this document would sorely test that maxim.

Organization of the Standards

Oklahoma's newly minted *Priority Academic Student Skills* (PASS) are offered for grades 1-8 and for these high school courses: Physical Science, Biology I, Chemistry, Physics, and Environmental Science. Within each grade or course, Oklahoma's learning expectations are divided into process/inquiry standards and content standards. The K-8 content standards are further subdivided into physical science, life science, and earth/space science standards. Finally, for all grades and courses, each standard is further specified by two or more learning objectives.

Content and Rigor

With rampant mistakes, critical omissions, and below-grade-level expectations, it seems that the content in the Oklahoma science standards could not have been written—or vetted—by anyone with a working knowledge of the natural world.

Scientific Inquiry and Methodology

Oklahoma presents seven process strands: observe and measure; classify; experiment and inquiry (which becomes "experimental design" in sixth grade); interpret and communicate; inquiry (which first appears in fourth grade); model; and engineering design. (The last two appear only in the high school course standards.) With some small exceptions, the inquiry standards for Kindergarten through eighth grade are presented logically, and their content and rigor progress well from grade to grade.

For example, here is how an item on measurement evolves over the grades:

> **Observe and measure objects, organisms and/or events using developmentally appropriate nonstandard units of measurement (e.g., hand, paper clip, book); and**

> **International System of Units (SI) (i.e., meters, centimeters, and degrees Celsius). (grade 1)**
>
> **Observe and measure objects, organisms, and/or events using developmentally appropriate International System of Units (SI) (i.e., meters, centimeters, grams, and degrees Celsius). (grade 3)**
>
> **Observe and measure objects, organisms, and/or events (e.g., mass, length, time, volume, temperature) using the International System of Units (SI) (i.e., grams, milligrams, meters, millimeters, centimeters, kilometers, liters, milliliters, and degrees Celsius). Measure using tools (e.g., simple microscopes or magnifier, graduated cylinders, gram spring scales, metric rulers, metric balances and Celsius thermometers). (grade 5)**
>
> **Identify qualitative and/or quantitative changes given conditions (e.g., temperature, mass, volume, time, position, length) before, during, and after an event. (grades 7 and 8)**

At the high school level, however, the process strands tend to be vapid. For example, the chemistry student is to:

> **Interpret data tables, line, bard, trend, and/or circle graphs from existing science research or student experiments.**
>
> **Determine if results of chemical science investigations support or do not support hypotheses.**
>
> **Evaluate experimental data to draw the most logical conclusion. (high school chemistry)**

The first of these is well below high school level; all three are vague to the point of uselessness—akin to asking someone to "read a novel and determine if it's good or bad."

Moreover, the process standards overwhelm the content standards. For example, as noted below, process standards take up four of the five-and-a-half pages devoted to high school physics.

In addition, among the seven process strands is one entitled "inquiry" that appears merely to restate skills and outcomes presented in the four strands that precede it. It would be better to eliminate this redundancy.

Finally, there is no mention of the historical or social aspects of science.

Physical Science

The physical science standards are rife with errors. For example, fourth graders are told that "electricity is the flow of electrical power or charge," which is simply wrong. Adding confusion to the standard, fourth graders have not been expected to learn the term "charge."

Also in fourth grade, students are told that "increasing the temperature of any substance requires the addition of heat energy." Again, this is wrong; it can also be done by adding work.

And Oklahoma's Hispanic students will have a chuckle when they are introduced, in eighth grade, to El Ninõ and La Ninã. Perhaps only in Oklahoma can the tilde move so far to the right!

Other standards are vague or confusing. Take, for example, the following:

> **Heat results when substances burn, when certain kinds of materials rub against each other, and when electricity flows through wires. (grade 4)**

What kinds of materials, exactly?

Similarly, students are told that "sound is a form of energy caused by waves of vibrations that spread from its source" (grade 4). What is meant by "waves of vibrations" is unclear.

In sixth grade, the distinction between kinetic and potential energy is introduced gratuitously and without context.

Chemical changes are introduced in eighth grade, following an introductory statement that has to do only with physical changes. But the introduction is a mere passing mention, in which the only new material is a mention of mass conservation in chemical reactions. Also in eighth grade is a brief section on motion and forces, in which the only new material is a mention that motion can be represented graphically. This is followed by a cryptic introduction of the law of inertia.

High School Physics

As mentioned above, vague process standards occupy four of the meager five-and-a-half pages devoted to high school physics (e.g., "interpret a model which explains a given set of observations"). And, while there are no errors, per se, the content presented is useless for any practical purposes. One standard covers force, including dynamics, gravitation, and electromagnetism. A second, without ever defining work or energy, covers energy conservation and, by implication, the second law of thermodynamics. The third standard attempts to define heat and covers all of waves, with a mention of machines and a definition of power tacked on. There is nothing about any other major areas of physics (e.g., modern physics).

High School Chemistry

The entirety of Oklahoma's high school chemistry standards amounts to a handful of inadequate generalities, half-thoughts, and errors, displayed on about a page and a half of text. Take, for example, the very first standard:

> **All matter is made from atoms. Its structure is made up of repeating patterns and has characteristic properties. The student will engage in investigations that integrate the process standards and lead to the *discovery of the following objectives*. (emphasis added) (high school chemistry)**

Of course, not all matter is made of repeating patterns, as evidenced by the existence of amorphous solids, liquids, and gases.

Furthermore, among the objectives students are meant to "discover" is the following:

> **Atoms are composed of subatomic particles (e.g., protons, neutrons, electrons, quarks). (high school chemistry)**

How, exactly, are students expected to discover subatomic particles? What's more, this is the first introduction that they've had to these subatomic particles. Surely protons, neutrons, and electrons should have been introduced in earlier grades.

Unfortunately, such problems are the rule, rather than the exception.

Finally, given the brevity of the standards, much important content is omitted, including: atomic models, spectra, electron transitions, metallic and hydrogen bonding, Lewis dot structures, molecular shapes and polarities, acids/bases, redox reactions, equilibrium, and carbon chemistry. The periodic law is nicely written, but there is no mention of the periodic table.

Earth and Space Science

Coverage of important earth and space science content is extremely thin. Astronomy, for example, is missing entirely. The word "star" never appears, nor do any cosmological topics. The standards include no description of the internal layering of Earth, though the word "crust" shows up a couple of times. The key topic of plate tectonics gets no more than a passing mention. And other topics are reduced to parenthetical lists, which are often incongruously different from or even irrelevant to the main statement. Take, for example, the following:

> **The processes of erosion, weathering, and sedimentation affect Earth materials (e.g., earthquakes, floods, landslides, volcanic eruptions). (grade 4)**
>
> **The solid crust of the earth consists of separate plates that move very slowly pressing against one another in some places and pulling apart in other places (i.e., volcanoes, earthquakes, mountain creation). (grade 7)**

None of these topics—erosion, weathering, sedimentation, earthquakes, floods, landslides, or volcanic eruptions—is developed in the standards, though students are expected to "engage in investigations that integrate the process standards and lead to the discovery of" some or all of them.

There is no high school earth and space science material, but only standards for a course in environmental science. The earth science content in that section is limited to the following:

> **Standard 1: The Physical Earth system – The Physical Earth system is determined by dynamic and static processes revealed through investigations of the geosphere, atmosphere, and hydrosphere. These interrelated processes are large-scale and long-term characteristics of the Earth that require knowledge of energy and matter. The student will engage in investigations that integrate the process standards and lead to the discovery of the following objectives:**
>
> **1. Composition and structure of the Earth is affected by an interaction of processes and events.**
>
> **a. Geologic processes affect the Earth over time (e.g., plate tectonics, erosion).**
>
> **b. Atmospheric processes affect the Earth over time (e.g., changes in daily weather conditions, convection/conduction/radiation, greenhouse effect, climate trends).**
>
> **c. Hydrologic processes affect the Earth over time (e.g., water cycle, ocean currents, ground water transport).**
>
> **d. Earth's current structure has been influenced by both sporadic and gradual events.**
>
> **2. Natural systems require a certain amount of energy input to maintain their organization (i.e., Laws of Thermodynamics). (high school environmental science)**

This omits or glosses over enormous swaths of important high school earth and space science content.

The environmental science standards do devote some attention to weather:

> **Weather exhibits daily and seasonal patterns (i.e., air temperature, basic cloud types – cumulus, cirrus, stratus, and nimbus, wind direction, wind speed, humidity, precipitation).**
>
> **a. Weather measurement tools include thermometer, barometer, anemometer, and rain gauge. (grade 5)**

Unfortunately, while the barometer is mentioned in this passage, air pressure is not. Indeed, the word "pressure" does not occur before high school, and when it does appear at the high school level, it is not in this context.

Life Science

If other content areas stumble, life science falls flat. A significant amount of content is excluded. A student could graduate from high school in Oklahoma without knowing how lungs work or the basics of photosynthesis, for example. And there is no mention of physiology whatsoever.

Making matters worse, the content that is provided is often slipshod and inadequately covered. Genes, for example, are mentioned in passing just twice:

> **Characteristics of an organism result from inheritance and from interactions with the environment (e.g., genes, chromosomes, DNA, inherited traits, cell division). (grade 7)**
>
> **A sorting and recombination of genes during sexual reproduction results in a great variety of possible gene combinations from the offspring of any two parents (i.e., Punnett squares and pedigrees). (high school biology)**

And students must wait until high school to learn that:

> **In multicellular organisms, cells have levels of organization (i.e., cells, tissues, organs, organ systems, organs). (high school biology)**

The treatment of evolution—the central principle of life science—is essentially absent. Biological evolution is reduced to "diversity of species"; the term "natural selection" appears once in the standards (in high school biology), while the term "evolution" cannot be found at all. The closest Oklahoma comes to teaching evolution is this fourth-grade standard, which appears in earth science, not life science:

> **Fossils provide evidence about the plants and animals that lived long ago. (grade 4)**

Given the severe limitations noted above, Oklahoma can earn no higher than a paltry one out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

Oklahoma's standards move at a painfully slow pace—repeating much content and often only changing a word or two as the standards progress from grade to grade.

Few standards are appropriately specific. What does it mean for fourth graders to "evaluate the design of a scientific investigation," or for sixth graders to "ask questions that can be answered through scientific investigation"?

And those standards that do attempt specificity often inject error. In high school chemistry, for example, the standards too often confuse more than they clarify. One standard uses the expression "molar weight proportions" without requiring students to know the mole concept. And the term "molar weight" is inaccurate; what was intended is either the microscopic term molecular weight—a term now supplanted by the more precise "molecular mass"—or perhaps the macroscopic term "molar mass." As noted above, there is no possibility of specificity in the extremely brief content standards for high school subjects.

Perhaps as a lagniappe, the overview of the Oklahoma standards presents the reader with a small (yet ignorant) Latin lesson:

> **Use of term i.e. means "in exactness"; use of the term e.g. means "example given."**

This would perhaps not be worth mentioning, were it not for the misuse of the abbreviations in the main text. As the following passage quoted in the earth and space science section above states: "Natural systems require a certain amount of energy input to maintain their organization (i.e., Laws of Thermodynamics)" (high school environmental science).

Given the almost complete uselessness of the Sooner State science standards, Oklahoma barely manages an average score of one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Oregon

GRADE	SCORES		TOTAL SCORE
F	Content and Rigor	1/7	2/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**0.8**
Scientific Inquiry & Methodology	2
Physical Science	2
Physics	0
Chemistry	0
Earth & Space Science	1
Life Science	0
Clarity & Specificity	**0.5**

Average numerical evaluations

Overview

At twenty-six pages, Oregon's *Content Standards* is relatively short, but the scientific content is even briefer, confined to a mere three pages. Brevity, in this case, is the soul of failure. Worse, it is essentially a cop-out. No statewide or local assessments could possibly be constructed on the basis of such sketchy information, nor could the meager content presented serve even as a strong foundation upon which a comprehensive curriculum could be built.

Organization of the Standards

Oregon offers science standards for each grade, K-8, and then for high school as a grade band. Within each grade, Oregon's science learning objectives are divided first into four "core standards" (commonly thought of as strands). Two of these core standards—structure and function, and interaction and change—cover "content knowledge." The remaining two—scientific inquiry, and engineering design—cover "process skills." These standards are explicitly intended to replace the traditional disciplinary categories, which are physical science, life science, earth and space science, and scientific inquiry.

Each of the four standards is then further explained by a series of learning objectives. Each learning objective is labeled with a P (physical science), L (life science), or E (earth and space science) to explain to which science discipline it relates.

Content and Rigor

The Oregon standards that address the three core content areas—physical science, life science, and earth and space science—consist of three pages, one for each content area. This means that a single page covers the totality of what Oregon students are expected to learn about each discipline in thirteen years of schooling.

We are told on page two that content specifications for the science standards will be developed in the future. Absent such a document, however, there is no way to know what Oregon expects its students to know and be able to do.

Document(s) Reviewed

- *Oregon Science K-HS Content Standards*. 2009. Accessed from: http://www.ode.state.or.us/search/page/?=2560

Scientific Inquiry and Methodology

The document proclaims that "it is essential that these standards be addressed in contexts that promote scientific inquiry, use of evidence, critical thinking, making connections, and communication." Yet no attempt is made to connect the process standards with content. History of science receives scant attention and is disconnected from all other matters.

Nor is there any real progression of content or rigor from grade to grade. In fact, in many cases, all that seems to be changing across grades is wording: Fifth graders are expected to "identify questions that can be tested" while the following year they "propose questions or hypotheses that can be examined through scientific investigation." More syllables, perhaps, but the idea is the same.

In 2005, we called Oregon's science process standards "perfunctory" and wrote that "their development in higher grades suggests little expectation of students' growth."[1] Sadly, the 2009 standards are equally poor.

Physical Science/High School Physics/High School Chemistry

Oregon provides no standards for high school physics or chemistry courses. Indeed, the word "chemistry" occurs nowhere in the document, and the word "physics" appears only in the name of the Oregon Physics Teachers Association.

There is some meager treatment of physical science, but even those standards omit many important topics, including: moles, balancing equations and stoichiometric calculations, gases, solutions, acids/bases/redox, mixtures, and equilibrium.

Oddly, the last item in the physical science standards asks students to "apply the laws of motion and gravitation to describe the interaction of forces acting on an object and the resultant motion" (high school). But this must logically be learned prior to nearly everything else in physics. And the fundamental principles of conservation of mass and energy are the two items immediately preceding the section on motion and gravitation. Indeed, six standards, written on eleven lines, cover the whole of high school (or is it junior high school?) physical science. How such Spartan attention could conceivably be sufficient in the eyes of the standards-writers is unfathomable. A Shakespearean sonnet takes up more ink.

[1] Paul R. Gross, *The State of State Science Standards 2005* (Washington, D.C.: Thomas B. Fordham Institute, 2005), http://www.edexcellence.net/publications-issues/publications/sosscience05.html.

Earth and Space Science

Once again, solid science content is notable only in its absence in this subject area. A string search does not turn up terms like plate, mountain, earthquake, volcano, convection, heat, seafloor spreading, mineral, rock, unit (except as in "instructional unit"), or theory. All of cosmology, solar system history, and planetary astronomy—that is, all of astronomy at every scale—is telescoped into the single sentence: "Describe how the universe, galaxies, stars, and planets evolve over time" (high school).

Life Science

The life science coverage is consistent with that of the other sciences. We have such sweeping generalities as these in fourth grade:

> **Compare and contrast characteristics of fossils and living organisms.**
>
> **Describe the interactions of organisms and the environment where they live. (grade 4)**

And in like manner in seventh grade:

> **Explain how organelles within a cell perform cellular processes and how cells obtain the raw materials for those processes. (grade 7)**

At the high school level, things get a little more specific, but not very much. Here is the entrée to evolution:

> **Explain how biological evolution is the consequence of the interactions of genetic variation, reproduction and inheritance, natural selection, and time. (high school)**

This would be a fine start, but there is absolutely no expansion of the five global ideas contained in this single sentence.

Oregon scrapes the bottom, earning a content and rigor score of one out of seven. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

To say that the Oregon standards are vague would be a ridiculous understatement. A two-page table titled "Vertical Articulation of the Core Standards" contains two columns, labeled "structure and function" and "interaction and change," which give some promise of content until one reads such empty entries as "living and non-living things move" or "the components and processes within a system interact."

At times, what passes for specifics in the Oregon standards amounts to gibberish. In eighth-grade earth and space science, for example, students are asked to "describe the processes of Earth's geosphere and the resulting major geological events." Students in fourth grade don't have it much better. They are expected to "compare and contrast the changes in the surface of Earth that are due to slow and rapid processes." Each of these standards conveys a pretty big order in a single global (pun intended) sentence.

In life science, students must "describe how asexual and sexual reproduction affect genetic diversity" and "explain how ecosystems change in response to disturbances and interactions." Such universal directives are no more useful in life science than they are in earth and space science.

Succinct this document is. Yet it simply cannot provide the kind of information needed to accomplish any real task of K-12 science education. Oregon's near abdication of the proper functions of science standards leads to its average score of barely one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Pennsylvania

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	2/7	3/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**2.3**
Scientific Inquiry & Methodology	0
Physical Science	4
Physics	2
Chemistry	3
Earth & Space Science	3
Life Science	2
Clarity & Specificity	**1.4**

Average numerical evaluations

Overview

The Pennsylvania science standards are generally poor. If a bright spot exists, it's in the earlier grades, where the coverage does occasionally earn reasonable marks for rigor. In high school, however, the material generally descends into flabbiness and disorder. By no means could these standards serve as the foundation for a sound science curriculum for students in the Keystone State.

Organization of the Standards

The Pennsylvania standards for grades 3-8 are first divided into four "standard categories": biological sciences; physical sciences; earth and space sciences; and science, technology, and engineering. (The inquiry and methodology standards are embedded in the science, technology, and engineering strand.) For each standard category the state provides "organizing categories," and then strands. For example, under "biological sciences," the first organizing category is "organisms and cells." Beneath that, the first strand is "common characteristics of life."

Finally, grade-specific "standard statements" are provided.

The high school standards are organized similarly—with the same standard categories, organizing categories, and strands—with one big caveat: Standards are not presented by grade level, but by course (physics, chemistry, biology) and by tenth- and twelfth-grade "targets for instruction and student learning." In other words, each of the three high school courses (physics, chemistry, and biology), as well as the tenth- and twelfth-grade expectations, addresses the material in each of the four standard categories listed above: biological sciences, physical sciences, earth and space sciences, and science, technology, and engineering. This presentation renders the high school material wildly confusing. Biology material, for example, appears within the biology course, within the chemistry course under the biological sciences standard category, and within the tenth- and twelfth-grade expectations.

No standards are provided for grades K-2, except within a broad K-4 inquiry grade band.

Document(s) Reviewed

- *Academic Standards for Science and Technology and Engineering Education: Elementary Standards*. June 2009. Accessed from: http://www.pdesas.org/main/fileview/Academic_Standards_for_Science_and_Technology_and_Engineering_Education_(Elementary).pdf
- *Academic Standards for Science and Technology and Engineering Education: Secondary Standards*. January 2010. Accessed from: http://www.pdesas.org/main/fileview/Academic_Standards_for_Science_and_Technology_and_Engineering_Education_(Secondary).pdf

Content and Rigor

The Pennsylvania science standards have many shortcomings, from a lack of grade-appropriate content across all disciplines to the inclusion of baffling and, at times, downright risible material.

Scientific Inquiry and Methodology

The Pennsylvania standards assert that "*Science as Inquiry* is logically embedded in the Science and Technology and Engineering Education standards [*sic*] as inquiry is the process through which students develop a key understanding of sciences." While this may be true, the document offers scant guidance as to how this is to be achieved. Process content is featured on a single page, organized into four grade bands (K-4, 5-7, 8-10, 11-12). Within each grade band, the state presents a series of bullet points (e.g., "compare and contrast scientific theories" [grades 8-10]) and then cross-references specific content-area strands to be examined. Yet, once identified among the content standards, those content strands merely direct the reader *back* to the single page overview, telling the reader to "See *Science as Inquiry* in the Introduction for grade level indicators." Thus, the inquiry standards, such as they are, include no link to real content, give no indication of just how these goals are embedded within the curriculum, and are functionally useless.

Also, missing entirely from the bulleted lists is any mention of the historical development of science.

Physical Science

The physical science standards suffer from two main problems. First, the expectations too often change very little from year to year, resulting in little progression of content or rigor as the grades advance. Take, for example, the following fourth- and fifth-grade standards:

> **Identify types of energy and their ability to be stored and changed from one form to another. (grade 4)**
>
> **Examine how energy can be transferred from one form to another. (grade 5)**

Here, the fifth-grade standard requires essentially the same level of understanding of energy transfer as the fourth.

There are some notable exceptions to this inertia of grade-to-grade development. A fine example is the treatment of dynamics:

> **Explain how movement can be described in many ways. (grade 3)**
>
> **Explain how an object's change in motion can be observed and measured. (grade 4)**
>
> **Explain how mass of an object resists change to motion. (grade 5)**
>
> **Explain how changes in motion require a force. (grade 6)**
>
> **Describe how unbalanced forces acting on an object change its velocity.**
>
> - **Analyze how observations of displacement, velocity, and acceleration provide necessary and sufficient evidence for the existence of forces. (grade 7)**
>
> **Explain how inertia is a measure of an object's mass.**
>
> **Explain how momentum is related to the forces acting on an object. (grade 8)**

Now, one may carp about the impracticality of teaching resistance to change in motion in fifth grade while deferring the discussion of force—the very thing that is being resisted—to sixth grade. But in the give-and-take of a real classroom, that will not be a problem. A more serious criticism is the final statement in eighth grade, which can lead to confusion between *impulse*, which is directly related to momentum, and *force*, which is related only indirectly. But overall, the development is refreshingly clear and pedagogically sound.

The second problem with the physical science standards is the way that some topics jump around from year to year, making it difficult to track the scope and sequence of content. Take waves as an example: Students study light in third grade, sound in fourth and fifth grades, nothing in sixth grade, light again in seventh grade, and nothing in eighth grade. Arbitrarily dividing this related content makes little sense. It would be better to study sound and light together year after year, which would help the student acquire insight into the nature of waves in general while at the same time deepening his or her understanding of the specific properties of sound and light.

High School Physics

The standards for high school physics are problematic. For starters, the ordering of items is bewildering. For example, the following mechanics content appears in the tenth-grade expectations—presumably before students will have taken high school physics (which typically happens in the eleventh grade):

> **Analyze the relationships among the net forces acting on a body, the mass of the body, and the resulting acceleration using Newton's Second Law of Motion.**

- **Apply Newton's Law of Universal Gravitation to the forces between two objects.**
- **Use Newton's Third Law to explain forces as interactions between bodies.**
- **Describe how interactions between objects conserve momentum. (grade 10)**

This detailed content belongs in the physics course itself, which in turn speaks to Newton's laws in only one standard:

> **Use Newton's laws of motion and gravitation to describe and predict the motion of objects ranging from atoms to the galaxies. (high school physics)**

What's more, the physics standards are devoted to a hodgepodge of applications that do violence to the natural logic and order of the subject. Take, for example, the following:

> **Differentiate among translational motion, simple harmonic motion, and rotational motion in terms of position, velocity, and acceleration.**

- **Use force and mass to explain translational motion or simple harmonic motion of objects.**
- **Relate torque and rotational inertia to explain rotational motion. (high school physics)**

This is a jumble of prerequisite material students will need for the study of kinematics and some applications of mechanics that follow on the essential introductory matters of Newton's laws.

And that's all there is of mechanics.

Sadly, equally chaotic and meaningless standards cover other important topics as well. For instance, students are asked to "explain how stationary and moving particles result in electricity and magnetism," or to "explain how electrical induction is applied in technology" (high school physics). Here, doubtless, the intent was to present electromagnetic induction. Electrical (or more properly electrostatic) induction has to do with the process of charging a dielectric object without touching it to a source of charge.

High School Chemistry

Chemistry, like physics, is confusing at the high school level. Aspects of the science are found in the chemistry course as well as in the tenth- and twelfth-grade expectations, leaving little confidence that students will learn the essentials.

What's more, standards that are included under the chemistry-course banner are sometimes overbroad and wildly ambitious, with students being asked to "explain the chemistry of metabolism" (high school chemistry). The chemistry of metabolism is a complex and wide-ranging subject; including this expectation adds little value. Other standards are simply hollow and represent failed attempts to link disciplines. For example, in a section devoted to photosynthesis and metabolism, the chemistry sub-strand includes the following:

> **Describe how changes in energy affect the rate of chemical reactions. (high school chemistry)**

This is meaningless; changes in the energy of what? Unfortunately, such entries are typical.

Oftentimes, content is too broad to be useful—or is missing entirely. And the list of material that fits this bill is entirely too long. It includes: gas law relationships; acid/base definitions and properties; neutralization reactions; pH scale; molarity; equilibrium; Le Châtelier's principle and stresses; equilibrium expressions and constants; organic chemistry, including types of bonding; names, shapes, and formulas of simple molecules; and solutions including preparation and dilutions. Phew!

Earth and Space Science

The earth and space science standards for elementary and middle school include some critical content. Stars and galaxies, for example, are well covered, as is the solar system:

> **Compare and contrast the size, composition, and surface features of the planets that comprise the solar system as well as the objects orbiting them. (grade 6)**

Unfortunately, lack of specificity often masks the intended scope. For example, in fourth grade, students are asked to "identify the layers of the earth." In seventh grade, this grows to "describe the layers of the earth." But it is unclear how "deep" the standards should go in either grade.

Further, some critical content is missing. The rock cycle is mentioned but not explained, and the major rock types—igneous, metamorphic, and sedimentary—are barely mentioned. Plate tectonics receives no more than a passing nod.

The high school standards are worse. For starters, there is no designated earth science course. Related standards are scattered between the tenth- and twelfth-grade expectations, but without a specific earth science course, it is unclear how such material would be presented to students. Even then, much is either glossed over or missing entirely. For example, astronomical units are not mentioned, nor are volcanism, climate and weather factors, or earthquakes. ("Seismic activity" is murkily defined in the glossary.) Plate tectonics is mentioned once each in fifth and tenth grades (and is incorrectly defined in the glossary), but never developed. Tenth-grade students are only asked to "relate plate tectonics to slow and rapid changes in the earth's surface." And the history of the universe is barely mentioned in tenth grade, when students are asked only to "provide evidence to suggest the Big Bang Theory."

Life Science

The life science standards are woefully inadequate. First of all, while some important content is included, there is no clear progression of content or rigor through the grades. For example, in fifth grade, students are asked to "explain the concept of the cell as the basic unit of life." Then, in seventh grade, they are asked to "explain how the cell is the basic structural and functional unit of living things." There is little difference between the two standards.

Second, too many expectations are nonsensical or so broad that they are essentially meaningless. For instance, seventh graders are asked to "explain why the life cycles of different organisms have varied lengths"—a question that may only have a theological answer!

Similarly, in eighth grade, students are asked to "explain mechanisms organisms use to adapt to their environment," a broad expectation that includes virtually no content.

In addition, much of the high school content simply demands too little of students. For instance, biology standards scattered among the tenth-grade expectations are pitched at such a low level that they do not merit discussion.

On the positive side, the high school biology course itself is far better, and much of the important content is covered with impressive depth and rigor. For example, students are asked to:

> **Describe how Mendel's laws of segregation and independent assortment can be observed through patterns of inheritance.**
>
> **Distinguish among observed inheritance patterns caused by several types of genetic traits (dominant, recessive, codominant, sex-linked, polygenic, incomplete dominance, multiple alleles). (high school biology)**

And later, students will:

> **Explain how the processes of replication, transcription, and translation are similar in all organisms.**
>
> **Explain how gene actions, patterns of heredity, and reproduction of cells and organisms account for the continuity of life. (high school biology)**

Unfortunately, these glimpses of excellence are rare, and some critical topics are missing even here. For instance, the standards contain no physiology at all, across all grades, so students will have no idea how their muscles and guts and brains work.

The treatment of evolution is nearly complete, with one notable omission. The previous version of Pennsylvania's science standards from 2002 laudably covered human evolution. Yet human evolution has been removed from this 2009 version of the Pennsylvania standards. Virtually no states cover human evolution; with this removal, Pennsylvania transitioned from being a pioneer to just another in the pack.

Overall, the Pennsylvania science standards are inadequate and earn a dismal average score of two out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

There are two significant problems with the Pennsylvania standards, both of which detract greatly from the clarity of the material. First, as noted above, the presentation of the high school content is wildly confusing. Physics, chemistry, and biology material appears scattered across three courses of the same names and across the tenth- and twelfth-grade expectations. The introduction to the *Secondary Standards* states:

> **In addition to course standards, the standards for grades 10 and 12 are shown to clarify the targets for instruction and student learning. Although the standards are not a curriculum or a prescribed series of activities, school entities will use them to develop a local school curriculum that will meet local students' needs.**

Unfortunately, this does little to clarify how the tenth- and twelfth-grade standards should be fitted into actual courses, and the scope and sequence of essential content is difficult to track.

In addition, the way some standards are written renders them meaningless. Some are far too broad: For instance, in fifth through seventh grades (but not at any higher level), students are asked to "use mathematics in all aspects of scientific inquiry." *All?* In eleventh and twelfth grades, they must "examine the status of existing theories," whatever that means. Other items in the standards are written in such vague language as to be incomprehensible, as in the glossary definition of the rock cycle: "The process by which rocks are formed, altered, destroyed, and reformed by geological processes and which is recurrent, returning to a starting point." It is a "process" made up of "processes" and returns to a starting point?

Other standards foster the insinuation of pseudoscience into science content by inviting teachers to "teach the controversy" about evolution and global warming, when delineating the specific scientific content they should learn would obviously be preferable.

In all, these drawbacks are significant and earn Pennsylvania an average score of one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Rhode Island

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	2/7	4/10
	Clarity and Specificity	2/3	

REPORT CARD

Content & Rigor	**1.8**
Scientific Inquiry & Methodology	0
Physical Science	3
Physics	0
Chemistry	0
Earth & Space Science	3
Life Science	5
Clarity & Specificity	**1.5**

Average numerical evaluations

Document(s) Reviewed

▶ *Rhode Island Science Grade-Span Expectations, K-12*. 2007. Accessed from: http://www.ride.ri.gov/instruction/gle.aspx#science

Overview

Rhode Island's life science standards are the sole bright spot in an otherwise poorly developed set of K-12 science standards that is riddled with errors as well as serious gaps and omissions of important content.

Organization of the Standards

The Rhode Island science standards are divided into three domains: life science, earth and space science, and physical science. These domains are then subdivided into ten statements of enduring knowledge (EK), four in life science and three each in the other two domains. EK statements cut across grade levels and are "intended to identify the fundamental knowledge/concepts for each domain of science." For example, the first EK for life science states:

> **All living organisms have identifiable structures and characteristics that allow for survival (organisms, populations, and species).**

Within the EKs, the standards are further explained by "assessment targets." Finally, for life science and earth and space science, the state provides grade-span expectations for grades K-2, 3-4, 5-6, 7-8, and 9-11. No distinct provision exists for chemistry, physics, or biology classes. Some grade-span expectations are labeled "example extensions" and are meant to be more challenging than the typical standard.

Each assessment target is also linked to one or more "unifying themes," which are broad principles (including inquiry, form and function, nature of science, and patterns of change) that cut across disciplines. For instance, there are ten unifying themes for inquiry, including "collect data" and "design, conduct, & critique investigations."

Content and Rigor

In spite of the rather elaborate structure described above, Rhode Island's standards are skeletal in content. They offer little in the way of scientific content or substance, leaving much assumed and unsaid. And what they do emphasize is often misguided.

Scientific Inquiry and Methodology

Scientific method and inquiry is covered in a single page, repeated in all three domain documents. These standards are represented through the state's six "unifying themes of science"—each with a series of bulleted sub-headings, notable only for their brevity. The nature of science section, for example, lists such categories as scientific theories, history of science, and science/tech/society, but no content is provided to indicate what, precisely, students should know and be able to do under each of these headings. "Scientific inquiry" exhorts students to "question and hypothesize," but the concepts of theory and hypothesis appear nowhere in the rest of the document.

In addition to these themes, which are specifically devoted to scientific inquiry and methodology, Rhode Island embeds process standards within its content expectations. While this effort is laudable, these process expectations are too vague to be helpful. For instance, one assessment target asks students to:

> **Sort/classify different living things using similar and different characteristics. Describe why organisms belong to each group or cite evidence about how they are alike or not alike. (grades K-4)**

While citing evidence is an important skill, in this context it adds little value. Students could just as easily be asked to list or describe similarities and differences.

Physical Science/High School Physics/High School Chemistry

Major concepts of physics are either omitted or glossed over. For example, the document goes into great detail about the study of energy without ever bothering to define it, even at the high school level. Electrostatics is not introduced until high school and electromagnetism is covered only briefly. Except for a passing mention in fifth and sixth grades, when students are asked to show "that electric currents and magnets can exert a force on each other," there is but one standard devoted it. The entire subject of mechanics is waved off with a single mention:

> **Students demonstrate an understanding of forces and motion by…using Newton's Laws of Motion and the Law of Conservation of Momentum to predict the effect on the motion of objects. (grades 9-11)**

Many important topics are subsumed under headings involving the term "energy." Although it is true that almost every physical process has something to do with energy, it makes little sense to use the term ubiquitously. These topics could readily be organized in a more useful manner.

Occasionally, something good appears—almost by accident. For instance, in third and fourth grades we read:

> **Students demonstrate an understanding of energy by…describing how heat moves from warm objects to cold objects until both objects are [*sic*] the same temperature. (grades 3-4)**

This standard is, in fact, a straightforward statement of the zeroth law of thermodynamics—something well worth knowing. (Though a student who understands this is not really "demonstrat[ing] an understanding of energy.")

In chemistry, the content is inadequate both in depth and progression through the grades. In Kindergarten through eighth grade, too much emphasis is placed on properties of substances and the conservation of matter/energy laws. Atoms are introduced in high school, yet elements and compounds occur earlier, in fifth through eighth grades. As noted above, separate physics and chemistry course content is not provided at the high school level.

Earth and Space Science

To their detriment, the earth and space science standards prefer broad statements to finer detail, and even the combination of "unifying themes" and linked "statements of enduring knowledge" offer little in the way of content. Worse, the content that is present is not particularly thorough or well-thought-out. Take, for example, the presentation of the rock cycle. In fifth through eighth grades, an assessment target asks students to do the following:

> **Using data about a rock's physical characteristics make and support an inference about the rock's history and connection to rock cycle. (grades 5-8)**

While some detail is included in this standard, the actual rock types are not even mentioned. In high school, the rock cycle gets another brief mention:

> **Students demonstrate an understanding of processes and change over time within earth systems by… explaining how heat (produced by friction, radioactive decay and pressure) affects the Rock Cycle [*sic*]. (grades 9-11)**

But the word "sedimentary" occurs in the standards only in the context of plate tectonic evidence, and "igneous" and "metamorphic" are not present.

Other important topics are missing as well. Weather and climate show up in the same sentence, but the relationship is not explained. Fossils are mentioned as "fossil evidence" but their formation is not addressed.

Still, there are a few bright spots: Space science—specifically astronomy and cosmology—fare somewhat better, with good mention of such subjects as stellar evolution, Doppler measurements of universal expansion, and the structure and function of the solar system.

The movement of the earth's plates is well handled in seventh and eighth grades, appropriately building off the standards that ask fifth- and sixth-grade students to understand the location of plate boundaries. But this line of standards regresses in high school: Discussion of mountain ranges is the only thing added, while "faults" have been watered down to "existing patterns."

Life Science

The life sciences are the sole bright spot in the Rhode Island standards. Even with the shortness of the standards document—life science runs a mere nineteen pages—the grade-span expectations generally cover important content with sufficient depth and rigor. Life requirements, respiration and photosynthesis, and cells and tissues are adequately handled. The greatest defect involves the treatment of reproduction, particularly meiosis. (In high school, this term is listed in the "example extensions" column but not in the main material, even though it is essential in explaining sexual inheritance patterns.) Human evolution receives good coverage from Kindergarten through eighth grade, but it is also mentioned only in the "example extensions" column—though one of the four life science EK statements is, "Humans are similar to other species in many ways, and yet are unique among Earth's life forms." In general, however, one comes away with the sense that some sound biology and evolution will be taught.

The strong coverage of important life science content helps Rhode Island eke out a pitiful average score of two out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Rhode Island standards are as vague as they are devoid of content. Too many fail to include the detail necessary to guide rigorous curricula and instruction. Take, for example, the following standard:

> **Students demonstrate an understanding of earth materials by…describing, comparing, and sorting rocks, soils, and minerals by similar or different physical properties (e.g., size, shape, color, texture, smell, weight, temperature, hardness, composition). (grades 3-4)**

It's not clear what students would look for in classifying minerals. Size and shape are arbitrary, color can vary and is not always important, and temperature will be whatever the room temperature happens to be. Texture and hardness make sense if they are properly defined in a way that third and fourth graders can manage, but it is not clear how students at this level would deal with composition.

In middle school, students are asked to:

> **Demonstrate an understanding of processes and change over time within earth systems by…explaining cause and effect relationships between global climate and energy transfer. (grades 7-8)**

A grandiose goal with no specifics, except for the tautological "hint" that energy transfer has something to do with climate (as it does with every other process).

In other cases, the standards are so general that they ask the impossible. Take, for example, the following high school standard, which distorts the meaning of thermodynamic efficiency:

> **Students demonstrate an understanding of energy by…explaining the Law of Conservation of Energy as it relates to the efficiency (loss of heat) of a system. (grades 9-11)**

Or this elementary school standard, which asks students to make an impossible connection between studying shadows and understanding energy:

> **Students demonstrate an understanding of energy by… demonstrating when a shadow will be created using sunny versus cloudy days. (grades K-2)**

Overall, these drawbacks earn Rhode Island an average score of two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

South Carolina

GRADE	SCORES		TOTAL SCORE
A-	Content and Rigor	**6/7**	9/10
	Clarity and Specificity	**3/3**	

REPORT CARD

Content & Rigor	**5.7**
Scientific Inquiry & Methodology	5
Physical Science	4
Physics	6
Chemistry	6
Earth & Space Science	6
Life Science	7
Clarity & Specificity	**3.0**

Average numerical evaluations

Document(s) Reviewed

- *South Carolina Science Academic Standards*. 2005. Accessed from: http://ed.sc.gov/agency/pr/standards-and-curriculum/Science.cfm

Overview

While too many states sacrifice clarity or content for the sake of brevity, South Carolina provides science standards that are clear and succinct, but that also outline most of the essential K-12 content that students need to learn.

Organization of the Standards

South Carolina provides grade-specific expectations for grades K-8 and course-specific expectations for high school physical science, biology, chemistry, physics, and earth science. These expectations are divided first into standards (with a parenthetical linking the standard to the domain of either life science, physical science, or earth science). Finally, grade-specific indicators are provided.

Included with these standards are a series of "support documents" that further clarify the grade-specific indicators and provide assessment guidelines for each indicator.

Content and Rigor

South Carolina has produced a set of workmanlike standards of consistent, high quality. Most disciplines cover all of the essential content with admirable thoroughness and attention to detail. Concepts develop over the advancing grades with clear and logical progression. This laudably systematic treatment reveals a firm scaffold upon which educators in the Palmetto State can build a science curriculum.

Scientific Inquiry and Methodology

The South Carolina inquiry standards are reasonably strong and include much of the essential content. In addition, the state has integrated critical process standards with content standards, making the link between the two clear. Unfortunately, by linking process with content, some important standards that should be repeated across strands are included only once. For example, high school physical science and biology students are asked to "generate hypotheses on the basis of credible, accurate, and relevant sources of scientific information." This is a critical skill that should not be limited to the study of physical science and biology, and yet it is not included among the expectations for physics, chemistry, or earth sciences. In the reverse, high school physics, chemistry, and earth science students are asked to use significant digits correctly, something that should *also* be asked of students in physical science and biology courses.

In addition, the standards make no mention of the historical development of science or of its role in modern life/society.

Physical Science

Virtually all essential physical science content for Kindergarten through eighth grade is included in the South Carolina standards, and is developed systematically, clearly, and cogently within and across grades. Take, for example, the development of magnetism, which first appears in Kindergarten:

> **Classify objects by observable properties (including size, color, shape, magnetic attraction, heaviness, texture, and the ability to float in water). (Kindergarten)**

The concept is then extended in second grade:

> **The student will demonstrate an understanding of force and motion by applying the properties of magnetism.**
>
> - **Use magnets to make an object move without being touched.**
> - **Explain how the poles of magnets affect each other (that is, they attract and repel one another).**
> - **Compare the effect of magnets on various materials.**
> - **Identify everyday uses of magnets. (grade 2)**

In fourth grade, we read:

> **Summarize the properties of magnets and electromagnets (including polarity, attraction/repulsion, and strength).**
>
> **Summarize the factors that affect the strength of an electromagnet. (grade 4)**

Then, in sixth grade:

> **Explain how magnetism and electricity are interrelated by using descriptions, models, and diagrams of electromagnets, generators, and simple electrical motors. (grade 6)**

Finally, in eighth grade:

> **Compare the wavelength and energy of waves in various parts of the electromagnetic spectrum (including visible light, infrared, and ultraviolet radiation). (grade 8)**

Similarly clear, thorough, and appropriately rigorous standards can be found throughout.

The high school standards that cover physical science are cleanly divided into segments covering chemistry and physics, and both are clear, thorough, and appropriately rigorous. The level of the material clearly implies that both subjects are intended for a ninth-grade course in physical sciences.

High School Physics

High school physics is divided into ten standards. The first five are required: scientific inquiry; mechanics; energy, momentum, conservation principles, and oscillations; electromagnetism; and waves. Of the remaining five, two are to be selected and taught. These are: sound; light and optics; modern physics; fluid mechanics; and thermodynamics. The division is conventional and logical; one may argue about whether optics, modern physics, and thermodynamics should be optional, but of course time constraints in the classroom are very real.

Each of these ten subjects is set forth in a systematic, logical, and solid manner. For example, mechanics is introduced with emphasis on kinematics and a brief introduction to Newtonian dynamics and its applications: vectors, one- and two-dimensional motion, Newton's laws, falling bodies, projectile motion, friction, rotation, and so forth.

A subsequent section introduces kinetic and potential energy, conservation principles, and power, followed by a brief treatment of momentum, collisions, and oscillatory motion.

The other necessary physics content is covered in a similarly systematic fashion.

High School Chemistry

The South Carolina standards include nearly all of the high school chemistry content one would expect to see, but they often lack the detail and clarity of the best state standards we have reviewed, as in the following:

> **Summarize the concept of equilibrium and Le Châtelier's Principle. (high school chemistry)**

What here tells the student specifically what she is expected to know? Is it the definition of equilibrium? Its dynamic nature? Equilibrium constants? Stress factors? Shifts? All of the above?

Chemical bonding is presented, but specifies only ionic and covalent bonds. Missing in the standards are metallic bonding and intermolecular forces like hydrogen bonding and dipole-dipole bonding.

Still, the topic of chemical bonding is enriched somewhat with related indicators:

> **Explain how the types of intermolecular forces present in a compound affect the physical properties of compounds (including polarity and molecular shape).**
>
> **Explain the unique bonding characteristics of carbon that have resulted in the formation of a large variety of organic structures.**
>
> **Explain the effect of electronegativity and ionization energy on the type of bonding in a molecule. (high school chemistry)**

Some topics are well addressed, including solutions, and acid/base solutions in particular:

> **Summarize the properties of salts, acids, and bases.**
>
> **Distinguish between strong and weak common acids and bases.**
>
> **Represent common acids and bases by their names and formulas.**
>
> **Use the hydronium or hydroxide ion concentration to determine the pH and pOH of aqueous solutions.**
>
> **Explain how the use of a titration can determine the concentration of acid and base solutions.**
>
> **Represent neutralization reactions and reactions between common acids and metals by using chemical equations. (high school chemistry)**

Overall, South Carolina has made a good attempt to provide the framework for a rigorous, academic, college-prep chemistry course. In the future, careful editing will move this set of chemistry standards from good to excellent.

Earth and Space Science

South Carolina offers students plenty of interesting material in earth sciences—notably in eighth grade and in astronomical topics at the high school level. For example:

> **Summarize the three layers of Earth—crust, mantle, and core—on the basis of relative position, density, and composition. (grade 8)**
>
> **Summarize the evidence that supports the big bang theory and the expansion of the universe (including the red shift of light from distant galaxies and the cosmic background radiation). (high school earth science)**

While the standards themselves are sometimes terse, the necessary content is fleshed out well in South Carolina's strong supporting materials. Further, the standards for Kindergarten through eighth grade lay a strong foundation for a rigorous high school curriculum. The following fifth-grade standard will provide some extra support for the study of plate tectonics later:

> **Illustrate the geologic landforms of the ocean floor (including the continental shelf and slope, the mid-ocean ridge, rift zone, trench, and the ocean basin). (grade 5)**

That said, there are a few holes and slip-ups. Some standards are so broad they become meaningless:

> **Explain how natural processes (including weathering, erosion, deposition, landslides, volcanic eruptions, earthquakes, and floods) affect Earth's oceans and land in constructive and destructive ways. (grade 5)**

And occasionally, the standards reinforce popular misconceptions. Take, for example, the following sentence in the eighth-grade support material:

> **Because earthquake waves travel faster through the mantle than through the crust, scientists know that the mantle is denser than the crust. (grade 8)**

Seismic velocity is actually inversely related to density.

Life Science

The coverage of life science from Kindergarten through eighth grade is reasonably solid and includes good coverage of genetics and physiology, as well as a strong introduction to evolutionary concepts.

In general, the high school biology materials are excellent, save for the complete omission of physiology: While the seventh-grade standards include strong coverage of this important topic, nothing appears after that year.

The coverage of evolution is occasionally evasive. For instance, while the eighth-grade standards do raise the important concepts of evolution, they do so without using the term. Further, natural selection shows up only in the support documents for that grade. Fortunately, at the high school level, evolution is treated excellently and the support documents are exemplary.

Overall, South Carolina has produced standards that are quite strong, and earn an average score of six out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The South Carolina standards are presented clearly and are nicely linked to support documents, which add significant value by providing specific details and clarifying what, precisely, students should know and be able to do. The one lapse in clarity is the use of such terms as “analyze,” “represent,” “identify,” “illustrate,” “infer,” “recognize,” and “distinguish”—instead of the words “know” and “calculate.” The use of these soft terms does not set forth a clear expectation of student performance or achievement, as in the following:

> **Illustrate the major structures of plants (including stems, roots, leaves, flowers, fruits, and seeds). (grade 1)**

Would drawing a picture suffice?

Taken together, these earn the South Carolina standards an average score of three out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

South Dakota

GRADE	SCORES		TOTAL SCORE
F	Content and Rigor	1/7	2/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**1.3**
Scientific Inquiry & Methodology	2
Physical Science	2
Physics	0
Chemistry	0
Earth & Space Science	2
Life Science	2
Clarity & Specificity	**1.0**

Average numerical evaluations

Document(s) Reviewed[1]

- *South Dakota Content Standards: Science*. 2005. Accessed from: http://doe.sd.gov/ContentStandards/index.asp

[1] Fordham's 2005 evaluation also reviewed South Dakota's 2005 content-standards document. Since 2005, we have updated and improved the evaluation criteria used to judge the standards. (See Appendix A for a complete explanation of criteria used in this review.) Through this new lens, South Dakota's science grade dropped from a D to an F. The complete 2005 review can be found here: http://www.edexcellence.net/publications-issues/publications/sosscience05.html.

Overview

South Dakota's extensive publication has plenty of words, but remarkably little scientific content. By no stretch of the imagination can it lead to a thorough and effective curriculum.

Organization of the Standards

The South Dakota standards are divided first into five strands: life science; earth and space science; physical science; nature of science; and science, technology, environment, and society. Each strand is then broken into "indicators," or sub-strands. Finally, grade-specific standards are provided for all grades, K-8. The high school standards are organized similarly, except that a single set of standards is provided for grades 9-12.

In addition, the state links each standard to a Bloom's Taxonomy level (comprehension, application, or analysis), a list of examples and supporting skills for the standard, and a series of performance descriptors that explain what student mastery should look like at advanced, proficient, and basic levels.

Content and Rigor

So much critical content is missing in every discipline that the gaps outnumber the useful material. And the latter, limited as it is, is marred by rampant error.

Scientific Inquiry and Methodology

The South Dakota standards begin by stating that science "is a process, not a recipe" and "is participatory, not passive knowledge acquisition." Perhaps so, but these bold claims are neutralized by the substance of the process standards presented. The "nature of science" standards offer precisely what has been rejected—a recipe consisting of bulleted lists of supporting skills. Teachers are urged to stay current with advances in science, as knowledge is "constantly changing and emerging." While it's certainly true that science teachers ought to pay attention to developments in the field, they should spend as much time, or more, learning about the history of science. Only by doing so will they be able to put into appropriate context any new discoveries.

While they do mention the history of science, the standards here are confused and unclear. Second graders are expected to "explore scientific contributions made by people" (as opposed, perhaps, to those made by machines?). The state then gives four examples: Benjamin Franklin, Thomas Edison, George Washington Carver, and the Wright brothers. Of course, while Franklin was a scientist (among many other things), Edison was primarily an inventor, Carver a chemical and agricultural engineer, and the Wrights engineers and inventors. This selection suggests a degree of confusion between science and technology that ought not to be conveyed to students, who need to understand the real connections between them and the lives and work of actual scientists.

Another standard asks fourth graders to "identify people who have revolutionized scientific thinking." Yet here, too, the examples of Morse and Edison speak more to patriotism than to actual scientific revolution. Surely, even ten-year-olds can be introduced to Copernicus, Newton, Darwin, or Pasteur (to name but four obvious examples).

This inattention to singling out important contributors to science is further exemplified in eighth grade. Here students are given the laudable goal of evaluating "important contributions to the advancement of science from people of differing cultures, genders, and ethnicity," a goal not forwarded by the inclusion of Neil Tice [*sic*] for astronomy. We suspect that Neil deGrasse Tyson would be disappointed. What the writers do not seem to know is that Tyson, though he is both a superb popularizer of science—astronomy in particular—and also African American, is not one of those whose contributions to the advancement of astronomy put him into the category of great astronomers. Why not choose Benjamin Banneker, whose almanacs were of utmost importance to both the astronomers and navigators of his time, or high-energy solar astronomer Arthur Walker II? And there are plenty of first-rate women astronomers, including Caroline Herschel, Annie Jump Cannon, Henrietta Leavitt, Jocelyn Bell, Margaret Burbidge, Carolyn Porco, and Angela Olinto.

Physical Science/High School Physics/High School Chemistry

South Dakota's Kindergarten through eighth grade physical science standards touch on most necessary content. But there are problems with just about every entry. For example, molecules first appear in fifth grade, but atoms don't show up until sixth grade. Displacement, a concept fundamental to kinematics, is never mentioned; velocity is found only in the high school standards and in the glossary.

As is the case throughout the South Dakota standards, the physical science materials for Kindergarten through eighth grade are awash in pedagogical jargon. Here is a typical example from fifth grade:

> **5.P.2.1** Students are able to **identify** forces in specific situations that require objects to interact, change directions, or stop.
>
> **Webb Level:** 1
>
> **Bloom:** Knowledge
>
> **Verbs Defined:** Identify – to select from given information
>
> **Key Terms Defined:** Forces in specific situations – a push or pull caused by gravitational forces
>
> **Teacher Speak:** Students are able to identify (to select from given information) forces in specific situations (a push or pull caused by gravitational forces) that require objects to interact, change directions, or stop.
>
> **Student Speak:** I can select from given information (identify) a push or pull caused by gravitational forces (forces in specific situations) that require objects to interact, change directions, or stop. (grade 5)

It is possible (though tedious) to extract a bit of science out of this, but that bit is not much to challenge the intellect of a fifth grader.

The high school standards include a general physical science section that seems to include basic concepts of both chemistry and physics and that is appropriate to a ninth-grade physical science course. A separate "advanced" section includes standards for both chemistry and physics that seem intended for the traditional college-prep chemistry and physics courses. Unfortunately, the presentation within these sections is a mess. The few standards that address physics are often riddled with errors, such as:

> Explain methods of transferring charge.
>
> Examples: induction, conduction, friction, electron guns (grades 9-12)

Neither electrostatic nor electromagnetic induction transfers any charge at all. Sadly, such examples the norm, rather than the exception, and the treatment of other branches of physics is either inadequate (e.g., waves and optics) or absent (e.g., thermodynamics).

Chemistry, too, is very thin. Anything approaching a high school chemistry course is contained in the "advanced high school physical science standards." Even at the advanced level, here is the only coverage of stoichiometry:

Students are able to perform stoichiometric calculations.

- **Convert between moles, mass, particles, volume.**
- **Calculate empirical and molecular formulas from mass percents.**
- **Determine limiting and excess reactants and percent yield in chemical reactions. (grades 9-12)**

The other four indicators that comprise high school chemistry go no deeper.

Earth and Space Science

Earth and space science does not present a more attractive face. The few content statements are usually vague, leading in most cases to no obvious content direction but sometimes veering off into too many. Missing are such key topics as the history of the universe or the solar system, stellar evolution, absolute and relative dating techniques, plate tectonics (though there is brief treatment of some of its consequences), volcanism, and any detail about the processes underlying climate and weather.

Life Science

Life science fares somewhat better, although it tends to get thinner with each advancing grade level. Aside from a mention of fossils in third grade, here is all the standards have to say about evolution:

Students are able to describe how genetic recombination, mutations, and natural selection lead to adaptations, evolution, extinction, or the emergence of new species.

Examples: behavioral adaptations, environmental pressures, allele variations, bio-diversity

- **Use comparative anatomy to support evolutionary relationships. (grades 9-12)**

In addition, the high school standards haphazardly mention, though never expand upon, some critical content at the advanced level. But it is hard to see how these concentrated statements could be used to inform an actual high school biology course. Take, for example, the following:

High school students performing at the advanced level:

- **Explain the steps of photophosphorylation and the Calvin cycle;**
- **Analyze chemical reaction and chemical processes involved in the Calvin cycle and Krebs cycle;**
- **Predict the function of a given structure;**
- **Predict the outcome of changes in the cell cycle;**
- **Explain how protein production is regulated;**
- **Predict how homeostasis is maintained within living systems;**
- **Predict how traits are transmitted from parents to offspring;**
- **Construct an original dichotomous key. (grades 9-12)**

What connection might there be between, say, a dichotomous key and the Calvin cycle, or between the regulation of protein production and the transmission of traits? The writers seem to have taken an index from a biology textbook, cut the individual entries apart, shuffled them, and laid them out in random order.

Taken together, these drawbacks earn South Dakota a disappointing average score of one out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The South Dakota standards take 200 pages to say virtually nothing of substance. Standards are overly broad and vague, and the supplementary material that is meant to clarify expectations rarely adds value. For example, vocabulary words and important terms are offered, but the definitions and explanations, particularly in earth and space science, are vague, incorrect, or confusing.

In addition, the performance descriptors, which ought to show how student understanding deepens from the basic to the advanced levels, are confusing. Normally, of course, students at each level can do everything at the level immediately preceding it, and they are working toward mastery of the knowledge and skills at the level that follows. But the descriptors offered in these standards seem barely correlated. For instance, in first grade the proficient student can "compare objects in terms of heavier or lighter," but no corresponding descriptor exists at the advanced level. In second grade, the advanced student can "predict the casting of shadows," "describe interactions of magnetic poles," and "describe ways heat can be produced," but nothing like these skills is to be found for either the proficient or the basic level. What is supposed to be going on as the student progresses from one level of proficiency to the next? It is impossible to tell.

Sadly, these examples are the norm, thus earning South Dakota an average score of one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Tennessee

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	3/7	4/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**3.0**
Scientific Inquiry & Methodology	2
Physical Science	4
Physics	2
Chemistry	4
Earth & Space Science	5
Life Science	1
Clarity & Specificity	**1.3**

Average numerical evaluations

Overview

The Tennessee science standards are clearly written—but their linguistic clarity too often is undermined by statements that are so broad they starve the passages of meaning. To make matters more confusing, Tennessee offers a bewildering array of high school courses. Taken together, these drawbacks make it impossible to infer what a student in the Volunteer State will know (or at least be expected to know) upon graduation.

Organization of the Standards

The Tennessee K-8 science standards are divided into five strands: inquiry, technology and engineering, life science, earth and space science, and physical science. Within each strand, a series of three to five "standards" is articulated. Then, beneath each standard, the state articulates a "conceptual strand" that is meant to define the "big ideas" within the strand that all students should grasp before they graduate from high school, as well as a series of guiding questions that are meant to "sharpen and inform instructional articulation." Finally, grade-level expectations (GLEs) are provided.

In addition, Tennessee provides suggested "checks for understanding," which are suggestions for how teachers can assess each GLE in the classroom, and "state performance indicators," which explain how each standard will be assessed by the state.

At the high school level, the standards are organized similarly, except that expectations are presented by course, rather than by grade, for thirteen different college-prep high school courses, five vocational courses, and five Advanced Placement courses.

Content and Rigor

The Tennessee standards contain islands of strength, but these get lost amid the overwhelming sea of disorder and confusion that more often characterizes the document. Furthermore, every discipline is missing critical content, some of them egregiously so. How this material could serve to build a rigorous K-12 science curriculum is difficult to imagine.

Document(s) Reviewed

- *Tennessee Elementary K-8 Science Standards*. 2007. Accessed from: http://www.tn.gov/education/ci/sci/index.shtml
- *Tennessee Secondary 9-12 Science Standards*. 2008. Accessed from: http://www.tn.gov/education/ci/sci/index.shtml

Scientific Inquiry and Methodology

The guiding question provided by the main inquiry standards asks students, "What tools, skills, knowledge, and dispositions are needed to conduct scientific inquiry?" And, while answers are given, they are so vague and formulaic that they fail to adduce the content that students would need to learn to conduct inquiry investigations. For example, grade-level expectations for Kindergarten, first, and second grade ask students to "explain the data from an investigation" or to "communicate understanding of simple data," but what that should look like in any of the three grades is never articulated. Not until high school is the concept of making and testing hypotheses even mentioned.

Coverage of the historical and social aspects of science is perfunctory. History is not presented at all in Kindergarten through eighth grade, and in high school students "trace the historical development of a scientific principle or theory"—to what end, though, remains unstated. Chemistry, biology, and physics at the high school level all include a standard on "embedded technology and engineering," with the guiding question, "How do science concepts, engineering skills, and applications of technology improve the quality of life?" Historical and ethical aspects of this question are avoided, beyond a vague expectation to "explore the impact of technology on social, political, and economic systems."

Physical Science

The physical science program is academically weak from Kindergarten through eighth grade. The standards frequently omit critical content and repetition within and between grades. For instance, heat and temperature are never defined, much less differentiated.

Vagueness is a problem throughout. For example, in fourth grade, students must "use appropriate tools to measure and compare the physical properties of various solids and liquids" and "compare the causes and effects of various physical changes in matter." This sort of hand-waving is of no use to those actually charged with instructing students.

Adding to these problems, the coverage of important topics is severely marred by incomprehensible statements and scrambling of logical sequences. This worsens in the higher levels, culminating in a simply awful handling of high school physics (more on this later).

In the high school physical science document, inconsistency reigns. Consider, for instance, the following sandwich of a thin slice of trivium between two slabs of sophisticated stuff:

> **Label a periodic table with oxidation numbers of main group elements, identify elements likely to form ions, and use information to construct formulas for compounds.**
>
> **Classify a substance as an element or compound based on its chemical formula or symbol.**
>
> **Explain ionic and covalent bonding based on the oxidation numbers of the elements in a compound. (high school physical science)**

Poor organization goes still further in damaging the internal logic of the subject. For example, electromagnetism and nuclear processes are subsumed under energy conservation—a bewildering choice.

High School Physics

In physics, the standards laudably (and unusually) present information in terms of mathematical equations. Unfortunately, they are set forth in an illogical, nearly nonsensical, and sometimes amusing hodgepodge. For example, the following sequence:

> **Experiment with elastic and inelastic collisions**
>
> > **Elastic : $m_1v_1 + m_2v_2 = m_1v_3 + m_2v_4$;**
> >
> > **Inelastic: $m_1v_1 + m_2v_2 = (m_1 + m_2)v_3$**
>
> **Distinguish between mass and weight using base units in the SI system.**
>
> **Associate time with the independent variable in most experiments. (high school physics)**

Aside from the fact that the subscript notation in the momentum conservation equations is poorly chosen and confusing, what in the world do the last two items have to do with the first, far more sophisticated one?

Thermodynamics is hopeless. Much is omitted, many unimportant matters are stressed, and the logical order more often than not is unruly or even completely inverted. The only section of physics that is not hopelessly scrambled is optics. While not perfect, it makes some sense:

> **Explore properties of electromagnetic radiation.**
>
> **Examine properties of light waves.**
>
> **Investigate the polarization of light.**
>
> **Investigate the optical properties of plane and curved mirrors**
>
> > **Focal length: $1/f = 1/d_o + 1/d_i$;**
> >
> > **Images in mirrors and lens: $m = h_i/h_o = (-d_i)/d_o$.**

Investigate the optical properties of plane and curved mirrors.

Draw, explain, and solve problems for the optics of mirrors and lenses.

Investigate optical phenomena (i.e., mirage, optical illusions, and dichromatic lens effect).

Solve problems related to Snell's law

Index of refraction: n = (sin θ_r / sin θ_i);

Snell's law: $n_i \sin \theta_i = n_r \sin \theta_r$.

Differentiate among transmission, reflection, refraction, diffraction, and interference of light waves.

Explore the formation of color (both additive and subtractive properties) [Additive Color Theory: W= B+G+R: Y= G+R: =B+G: M = R+B; Subtractive Color Theory: B=W–Y: C= W–R: M=W–G]. (high school physics)

Missing, however, are interference and diffraction (though the section begins with a discussion of the wave nature of light, which should be a fine way of introducing these subjects).

High School Chemistry

Of the two courses covered, Chemistry I appears to be aimed at the traditional high school chemistry course, while Chemistry II is an advanced or honors course. Many of the standards in Chemistry I are well stated—both specific and clearly written. Unfortunately, many others are poorly crafted, or pitched below the level of high school chemistry, or offer spotty coverage of their subject matter. For example, atomic bonding lacks material on the critical topics of hydrogen and metallic bonding; kinetic molecular theory is addressed but the ideal gas law is not; acid-base chemistry is weak and redox reactions are not mentioned; and there is nothing on equilibrium or Le Châtelier's principle, so it is odd to see mention of the use of a solubility product table.

Earth and Space Science

The coverage of earth and space science in Kindergarten through eighth grade is reasonably thorough. The solar system is introduced in third grade and expanded in fourth grade. The universe on the large scale is, however, not mentioned at all.

The Earth's structure, and such effects of plate tectonics as earthquakes, orogeny, and seafloor spreading, are introduced adequately, if a bit late, in seventh grade. The same is true of the rock cycle and mineralogy. The basics of climate and weather are introduced nicely in fourth grade. But it is not easy to tell what students will learn about earth and space science in high school, owing to the wide selection of courses within the category.

Earth science and geology are separate courses, and the treatment of geology in particular has many positive aspects, chief among them a strong section on maps. Although the rigor of many of the standards is far too low for the grade level, some topics—including such high-level topics as crystal systems, systematic mineralogy, and Bowen's Reaction Series—are treated with admirable depth and rigor.

The earth science course covers astronomy at all scales of distance quite thoroughly, beginning with, "Identify the components of the universe: black holes, galaxies, nebulae, solar systems, stars, planets, meteors, comets, and asteroids (high school earth science)," and working down in scale to the effect of the moon and the sun on the Earth's tides.

Life Science

The life science standards suffer from several significant challenges, beginning with poor and repetitive treatment of evolution from Kindergarten through eighth grade. For example, a single guiding question is used to frame every grade, from Kindergarten through grade eight: "How does natural selection explain how organisms have changed over time?"

Fossils are introduced early and often, which is good. Yet by fourth grade the writers seem to have run out of fossil topics. Meaningful statements are replaced by the vague generality, "Gather fossil information to draw conclusions about organisms that exist today," with no indication of what information students should use, or what conclusions students should draw. In fifth grade and beyond, the standards simply repeat concepts previously covered, using different words but with no increase in depth or rigor. For instance, the following standard asks fifth-grade students to:

Analyze fossils to demonstrate the connection between organisms and environments that existed in the past and those that currently exist. (grade 5)

Unfortunately, that task is essentially identical to standards that preceded it in second grade and fourth grade, respectively:

Compare pictures of fossils with animals or plants that are living today. (grade 2)

Gather fossil information to draw conclusions about organisms that exist today. (grade 4)

There is a potentially promising exercise at eighth grade: "Create a timeline that illustrates the relative ages of fossils in sedimentary rock layers" and "compare fossils found in sedimentary rock to determine their relative age." Yet the terms "evolution" and "natural selection" are not used. In Biology I, we see the same tendency toward evasion:

> **Apply evidence from the fossil record, comparative anatomy, amino acid sequences, and DNA structure that support modern classification systems. (Biology I)**

And just what are those modern classification systems and what is the basis on which they are built? Tennessee students will never know. Given that biology is an elective in high school and half the biology course options in high school do not entail evolution, it's pretty easy never to learn about it in Tennessee.

Sadly, most important life science topics receive similarly slipshod coverage, with standards that are so vague that they are virtually without content. For instance, seventh-grade students are asked to:

> **Describe the function of different organ systems. (grade 7)**

and

> **Investigate the relationship among DNA, genes, and chromosomes. (grade 7)**

Unfortunately, these expectations provide nothing specific that could be useful to classroom application.

Tennessee presents four biology courses at the high school level: Biology I, Biology II, Human Anatomy and Physiology, and Ecology. Among the four, only Biology II even attempts to cover the full scope of biology, but even there, the standards are often vague and repetitive. Worse still, it isn't clear that all students are required to take Biology II, which means that students could graduate from Tennessee high schools without having been exposed to much of the essential life science content.

Taken together, these flaws earn Tennessee an average score of three out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The clarity of the document does not extend much further than expressing confusion in a grammatically and syntactically correct way. The result is a sort of linguistic bluff: a well-written document that says very little of substance.

Too often, the absence of small details derails an entire statement. For example, in high school chemistry, students must:

> **Determine the colligative properties of a solution based on the molality and freezing point or boiling points of the solvent. (Chemistry I)**

What this confusing statement means is, "calculate the boiling point elevation or the freezing point depression of the solution." An equally confusing statement asks students to:

> **Use calorimetry to: identify unknown substances through specific heat, determine the heat changes in physical and chemical changes, determine the mass of an object, and determine the change in temperature of a material. (Chemistry I)**

Why not simply: "Use the heat capacity equation $Q = mc\Delta T$ to identify a substance by measuring its specific heat capacity in a calorimeter"?

Or consider the following scramble from the physics material:

> **Investigate the definitions of force, work, power, kinetic energy, and potential energy.**
>
> - **Force: F = ma;**
> - **Work: W = Fd;**
> - **Power: $P = (F\Delta d)/\Delta t$;**
> - **Kinetic Energy: $E_K = 0.5mv^2$;**
> - **Potential Energy: $E_P = mg\Delta h$. (high school physics)**

$F = ma$ is not the definition of force, nor is $E_P = mg\Delta h$ the definition of potential energy. And lumping these equations together adds little value, other than to demonstrate that the writers know them.

Such examples are far from rare. As a result, Tennessee earns an average score of one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Texas

GRADE	SCORES		TOTAL SCORE
C	Content and Rigor	5/7	6/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**5.0**
Scientific Inquiry & Methodology	7
Physical Science	5
Physics	4
Chemistry	5
Earth & Space Science	6
Life Science	3
Clarity & Specificity	**1.0**

Average numerical evaluations

Overview

Texas has produced a set of science standards with areas of strength—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.

Organization of the Standards

The *Texas Essential Knowledge and Skills for Science* (TEKS-Science) consists of a series of rather lengthy outlines that frequently repeat themselves. Standards are presented for each grade, K-8, as well as for eight different high school courses, including biology, chemistry, physics, and integrated physics and chemistry. Further, Texas provides standards for AP Biology, AP Chemistry, AP Physics (both B and C), and AP Environmental Science, as well as for IB Environmental Systems.

For grades K-8, standards are divided into five strands: scientific investigation and reasoning; matter and energy; force, motion, and energy; earth and space; and organisms and environments. Each strand is then divided into one or more sub-strands. Finally, grade-specific standards are provided for each sub-strand.

The high school standards are organized similarly, with two exceptions. First, they are provided by course, rather than by grade. And second, within each course, there are only two strands: scientific processes and science concepts.

One concern with the high school standards is that, in addition to the science courses that are typically offered (chemistry, physics, and biology), the state provides standards for several electives: aquatic science, astronomy, earth and space science, and environmental systems. If students took all of those courses, they would learn a wealth of critical science content. Unfortunately, it's not clear how many of these courses students must take. For the purposes of this review, therefore, we focus mainly on the conventional courses and not the electives.

Document(s) Reviewed

- *Texas Essential Knowledge and Skills for Science*. 2010. Accessed from: http://ritter.tea.state.tx.us/rules/tac/chapter112/index.html

Content and Rigor

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.

Scientific Inquiry and Methodology

The scientific inquiry and methodology standards are clear, practical, and grade-appropriate, and the content builds well from grade to grade.

History of science is well covered throughout, starting in third grade, when students are asked to "connect grade-level appropriate science concepts with the history of science, science careers, and contributions of scientists." Here, the explicit connection between conceptual and historical is to be welcomed.

The high school standards are equally strong. Students are expected to evaluate the impact of science on society and the environment and continue their examination of the history of the field. The standards are almost always placed in the context of benchmarks that set reasonable and specific expectations.

Physical Science

The quality of the physical science standards varies dramatically from the highly rigorous and grade-appropriate to the frustratingly general. On the positive side, the terms potential and kinetic energy first appear in sixth grade, and students are expected to differentiate between them. The law of conservation of energy is also well covered, but no mention is made of work or of the work-energy theorem.

Unfortunately, the organization of the physical science standards is problematic. No dedicated physical science strand exists; rather, related content is lumped into one of two categories: "matter and energy" and "force, motion, and energy." As a result, important content is arbitrarily shoehorned into one or the other of these. For example, electromagnetism is subsumed under "force, motion, and energy," for no better reason than that it has to be put somewhere.

Several topics suffer glaring gaps and omissions. Energy, for example, is introduced in fourth grade, but no effort is made to define it, even loosely.

In seventh grade, students are asked to:

> **Illustrate the transformation of energy within an organism such as the transfer from chemical energy to heat and thermal energy in digestion. (grade 7)**

The idea of connecting chemical thermodynamics with metabolism is a good one, but it is marred by the phrase "heat and thermal energy," implying that these are two different things.

The failure to define and develop key concepts is a nagging problem for the physical science material. The term "heat" or "heating" is used some eighteen times from Kindergarten through eighth grade without explanation or connection to particle motion. The term "temperature" is used nine times in those grades but with no discussion of its connection to average molecular kinetic energy. And on the chemical side of physical science, molecules are mentioned in three places, but nowhere is it explained that molecules are made up of atoms. And there is no reference to crystals, let alone their structure.

High School Physics/High School Chemistry

We consider high school physics and chemistry in a single section because of the unconventional way they are blended in the Texas standards. At the high school level, Texas offers Integrated Chemistry and Physics for one credit, specifying that it is intended for ninth or tenth graders. However, the standards contain little that has not already been seen in the middle school grades. There is also a separate chemistry course, recommended for tenth, eleventh, or twelfth grades, and a separate physics course, recommended for ninth, tenth, eleventh, or twelfth grades, with lesser math requirements than the chemistry course. This is unconventional, since the common order of courses is chemistry followed by physics (which is more math-intensive).

In the high school physics course, kinematics and dynamics are introduced systematically and clearly. However, they tend to avoid simple equations that would make the material even clearer and more concise.

There is no systematic coverage of the laws of electromagnetism—Coulomb's, Ampère's, and Faraday's laws in particular. Thermodynamics and kinetic theory are covered, though in a manner far from what would be useful to build a curriculum.

Oscillations, waves, optics, and modern physics receive only sketchy treatment.

Other standards are redundant, riddled with errors, or both. Take, for example, the following:

> **Understand the electromagnetic spectrum and the mathematical relationships between energy, frequency, and wavelength of light. (high school chemistry)**

> **Calculate the wavelength, frequency, and energy of light using Planck's constant and the speed of light. (high school chemistry)**

For starters, students need to know *either* the wavelength or frequency in order to calculate the energy; these variables cannot be found by just knowing the two constants. In addition, these standards are largely redundant. What is missing is a specific listing of what students should know about the electromagnetic spectrum and the connection of spectra to atomic electron transitions.

The quality of the chemistry standards varies widely, from absent to inadequate to excellent. On the one hand, the Texas standards commendably cover several important topics that many other state standards ignore. Those include: accuracy and precision, dimensional analysis, scientific notation, empirical and molecular formulas, the malleability and ductility of metals, and calculations of isotopic composition and atomic mass.

There are, however, substantial gaps. Rates of reaction and chemical equilibrium, for example, are omitted. Also missing is any mention of organic chemistry beyond the sketchy statement that "organic compounds are composed of carbon and other elements," which appears not in high school chemistry, but in seventh grade.

Some of the chemistry standards address topics that are not appropriate for high school. For instance, students are asked to "compare solids, liquids, and gases in terms of compressibility, structure, shape, and volume," a task that younger students could surely handle. By contrast, students are also asked to "classify matter as pure substances or mixtures through investigation of their properties," an expectation that is likely too difficult and time consuming for high school chemistry.

Earth and Space Science

The material for earth and space science is strong, appearing at appropriate grade levels and with sufficient depth. Though a few areas are relatively weak—including aspects of the mechanisms of plate tectonics, earthquakes, and volcanoes—other content is presented with admirable depth and breadth.

Some topics are well introduced, but not adequately developed. For example, students are introduced to the rock cycle in sixth grade, but the standards never discuss the crucial issue of how those processes form a cycle:

> **Classify rocks as metamorphic, igneous, or sedimentary by the processes of their formation. (grade 6)**

The high school earth and space material is especially strong, and much content is covered with depth and rigor. Take, for example:

> **Analyze how gravitational condensation of solar nebular gas and dust can lead to the accretion of planetesimals and protoplanets. (high school earth and space science)**

One may quibble about the instruction to "analyze how"—we presume the intended meaning is simply "explain how"—but the subject is important and appropriate. Similarly strong examples can be found throughout.

To its credit, Texas also dispassionately and unapologetically introduces students to global warming, a political hot potato in many places, with the following:

> **Analyze the empirical relationship between the emissions of carbon dioxide, atmospheric carbon dioxide levels, and the average global temperature trends over the past 150 years. (high school earth and space science)**

Life Science

In stark contrast to some other disciplines, the Texas life science standards are woefully imbalanced, with poorly developed material in the early grades and strong, sometimes excellent, content in the upper levels.

The subjects of food webs and life cycles, and the idea that offspring are like parents, appear several times from Kindergarten through fifth grade. Unfortunately, there are only minor wording changes—and therefore little increase in depth—over this considerable grade span. Then, out of the blue, fifth-grade students are asked to:

> **Identify the significance of the carbon dioxide-carbon cycle to the survival of plants and animals. (grade 5)**

Given the paucity of prior information, one wonders how this will be accomplished.

Evolution is all but ignored from Kindergarten through fifth grade, save a sentence in the earth and space science section that asks students to "identify fossils as evidence of past living organisms" (grade 5).

The middle school standards are marginally better, but still problematic. For example, seventh graders should learn that:

> **Populations and species demonstrate variation and inherit many of their unique traits through gradual processes over many generations. (grade 7)**

Unfortunately, this is simply wrong. Traits are inherited directly at each generation; there's nothing gradual about it. Students are then asked to explain variation within a population or species by examining external features that enhance survival. Such examinations will yield no explanation of variation.

Perhaps the biggest problem with the middle school standards, however, is their coverage of evolution. For instance, the seventh-grade standards mention the Galapagos finches, giving the impression that the Darwinian paradigm is being presented. Unfortunately, it is not. Instead, the example of the finch *Geospiza fortis* apparently refers to studies by Peter and Rosemary Grant on beak size in this species, made widely known by Jonathan Weiner's Pulitzer Prize-winning book, *The Beak of the Finch*. Creationists often distort these important findings to argue that Darwinian macroevolution does not occur—instead, microevolution does. In addition, the word "evolution" is never used in any of the middle school standards, and the term "natural selection" is never explained.

In spite of the Texas Board of Education's erratic approach to evolution, the state's current high school biology standards handle the subject straightforwardly. There are no concessions to "controversies" or "alternative theories." In fact, the high school biology course is exemplary in its choice and presentation of topics, including its thorough consideration of biological evolution. Even so, the term "natural selection" appears just three times, as does the word "evolution" and its variants. It is hard to see how Texas students will be able to handle this course, given the insufficient foundations offered prior to high school.

In contrast to the confusion of the taxonomic material in sixth grade, the high school standards present a straightforward, if somewhat old-fashioned, version of how taxonomies are constructed.

The only major lapses at the high school level are the rather cursory mentioning of photosynthesis, but not respiration, and the inadequate coverage of genes.

Taken together, the combination of strengths and weaknesses earns the Lone Star State a solid score of five out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

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. Take, for example, the following process standards:

> **Contrast situations where work is done with different amounts of force to situations where no work is done such as moving a box with a ramp and without a ramp, or standing still.**
>
> **Demonstrate and illustrate forces that affect motion in everyday life such as emergence of seedlings, turgor pressure, and geotropism. (grade 7)**

What these mean is a mystery.

The problem of ambiguity is particularly acute in the physical science material. In fourth grade, for instance, students are expected to:

> **Demonstrate that electricity travels in a closed path, creating an electrical circuit, and explore an electromagnetic field. (grade 4)**

But how fourth graders are supposed to identify, much less explore, an electromagnetic field is unstated, as is how that directive got jammed in with a straightforward item on electric circuits. Equally nebulous standards can be found throughout.

Similarly, too many standards across disciplines ask students to "observe" or "explore," with no indication of what these directions mean or how they are to be measured.

Finally, the organization of the standards is confusing, with related expectations scattered across various strands and sub-strands, making it difficult to track the scope and sequence of important content.

Still, the Texas standards say enough in a sufficiently straightforward manner to earn a one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Utah

GRADE	SCORES		TOTAL SCORE
B	Content and Rigor	5/7	7/10
	Clarity and Specificity	2/3	

REPORT CARD

Content & Rigor	**4.8**
Scientific Inquiry & Methodology	5
Physical Science	4
Physics	4
Chemistry	5
Earth & Space Science	5
Life Science	6
Clarity & Specificity	**2.1**

Average numerical evaluations

Document(s) Reviewed

- *Utah Elementary Science Core Curriculum: K-2*. 2010. Accessed from: http://www.schools.utah.gov/CURR/main/Core-Curriculum/By-Subject/K-2ScienceCoreCurriculum.aspx
- *Utah Elementary Science Core Curriculum: 3-6*. March 2002. Accessed from: http://www.schools.utah.gov/CURR/main/Core-Curriculum/By-Subject/Scie3-6.aspx
- *Utah Secondary Science Core Curriculum: 7-8*. April 2003. Accessed from: http://www.schools.utah.gov/CURR/main/Core-Curriculum/By-Subject/Scie7-8.aspx
- *Utah Secondary Science Core Curriculum: 9-12*. April 2003. Accessed from: http://www.schools.utah.gov/CURR/main/Core-Curriculum/By-Subject/Scie9-12.aspx

Overview

The Utah standards do many things well; clear language and rigorous, grade-appropriate content predominate. Yet this generally solid effort is dogged by vague or incomplete statements, and some inaccurate or missing material.

Organization of the Standards

The Utah science standards are presented in four documents, each covering a different grade span: K-2, 3-6, 7-8, and 9-12. The standards for grades 3-12 were adopted between 2002 and 2003, along with a set of “integrated” K-2 standards, which lumped the science standards together with those for fine arts, social studies, health, and physical education. In 2010, Utah replaced the integrated K-2 standards with science-specific content standards.

The K-2 document stands apart from the rest. It divides material first into four “big ideas”: the processes, communication, and nature of science; earth and space science; physical science; and life science. Each big idea is then divided into grade-specific objectives, which are then described by indicators.

The material for grades 3-8 is presented by grade, and the high school material is presented by course. The standards documents each begin with a description of six “intended learning outcomes” (ILO), common across all grades and courses, which describe the process outcomes that students should achieve. For instance, students will “manifest scientific attitudes and interests” or “use science process or thinking skills.” Each of the six general ILOs is then followed by grade- or course-specific outcomes. Apart from the ILOs, expectations are divided into grade- and course-specific series of benchmarks, standards, objectives, and indicators.

Third grade focuses on relationships, motion, and cause and effect. Fourth grade examines Utah’s natural history, and fifth grade looks at change and cause and effect. Sixth grade deals with scale and relative position. Grades seven and eight are integrated courses, while the high school standards are divided into earth systems, biology, chemistry, and physics.

Content and Rigor

The content that is covered in the Utah standards is generally thorough and scientifically accurate. Unfortunately, some critical content is missing, particularly in the higher grades, and excessive repetition undermines the overall effectiveness of the standards.

Scientific Inquiry and Methodology

The difference between the K-2 and 3-12 process standards is noteworthy. The former are strong—the objectives and indicators are clear and they are tied to specific content. In addition, the state offers guidance for combining process and content (as well as introducing themes from science, technology, and society). The only weak point is the reference to "ideas in science" and that "ideas are supported by reasons"—surely more precise language should be used even at these early grades.

Unfortunately, the standards for grades 3-12 are far weaker. For starters, the intended learning outcomes are vague to the point of meaninglessness. For instance, by the end of third grade, students will "demonstrate a sense of curiosity." Only a small handful of the ILOs are specific, and several seem out of place. For instance, by the end of fifth grade, students will "accept and use scientific evidence to help resolve ecological problems."

History gets a clear mention at the high school level—"relate the nature of science to the historical development of the theory of evolution"—but not at earlier grades.

Physical Science

Physical science presents a mixed picture. Magnets and magnetism are introduced relatively late, in fifth grade, with observations and activities that should be completed earlier. But laudably, electrostatic phenomena and circuit construction are introduced in tandem with them, which gives students an uncommonly early insight into the important complementarity of magnetism and electricity. Heat, optics, and sound are treated in a substantial and systematic way in sixth grade.

Yet the eighth-grade physical science material does not measure up. Take the following example:

> **Investigate the application of forces that act on objects, and the resulting motion.**
>
> **a. Calculate the mechanical advantage created by a lever.**
>
> **b. Engineer a device that uses levers or inclined planes to create a mechanical advantage.**
>
> **c. Engineer a device that uses friction to control the motion of an object.**
>
> **d. Design and build a complex machine capable of doing a specified task.**
>
> **e. Investigate the principles used to engineer changes in forces and motion. (grade 8)**

None of these examples gets at the objective, which really has to do with Newton's second law.

High School Physics

High school physics begins with an excellent development of kinematics and dynamics. For example, Newton's first law of motion is stated thus:

> **The motion of an object can be described by measurements of its position at different times. Velocity is a measure of the rate of change of position of an object. Acceleration is a measure of the rate of change of velocity of an object. This change in velocity may be a change in speed and/or direction. Motion is defined relative to the frame of reference from which it is observed. An object's state of motion will remain constant unless unbalanced forces act upon the object. This is Newton's first law of motion. (high school physics)**

Missing, unfortunately, are the quantitative statements essential to physics at this level. Likewise, Newton's law of gravitation and Coulomb's law are presented in a flurry of circumlocution instead of as two simple equations. Words are important, but at the high school level they cannot replace direct quantitative statements.

The physics standards section does not purport to be encyclopedic: "Not all possible physics topics are specified in the [standards]. Teachers may enhance their individual classes as they see opportunities to include more topics or more depth." Yet too many critical subjects are absent. Kinematics, dynamics, and energy conservation are well covered, and thermodynamics, electromagnetism, light, and sound get at least some attention. Totally absent, however, are planetary dynamics and Kepler's laws, modern physics (including significant products like transistors, lasers, and nuclear power generators), fluid flow, and kinetic theory.

In the material that is present, the level of expectation is often low. For instance, students are asked to "identify the relationship between the speed, wavelength, and frequency of a wave" (high school physics). A physics student ought to be able to do more than merely "identify" the relation $v = f\lambda$.

High School Chemistry

The chemistry curriculum lists six standards, each with its own objectives and indicators. Many of these are quite good and clearly written—as is the case with the standards dealing with both equilibrium and solutions. Still, many others are not. In particular, some important topics are either missing or incomplete.

Organic chemistry, for example, does not get even a mention. The elementary organic compound methane is given as an example in one of the objectives, but in a completely different context. Kinetic molecular theory and the gas law relationships (including the ideal gas law and molar volume) are missing completely. These are serious omissions.

In one objective, students are asked to describe the shape and polarity of water, ammonia, and methane molecules from a given model. But there is no mention of Lewis dot structures, molecular polarity is not defined, and limiting this topic to only these three molecules is setting the bar quite low.

Worse, there is no requirement that students be able to write and balance chemical equations. The requirement that students be able to "use a chemical equation to describe a simple chemical reaction" (high school chemistry) is not specific enough. Terms such as molar proportions and molar relationships are given, but the definition of mole is not.

Earth and Space Science

Earth and space science fares better, especially in elementary and middle school. Earth structure and history and cosmology are covered well. For example, here is what eighth graders learn about fossils:

> **Describe how rock and fossil evidence is used to infer Earth's history.**
>
> **a. Describe how the deposition of rock materials produces layering of sedimentary rocks over time.**
> **b. Identify the assumptions scientists make to determine relative ages of rock layers.**
> **c. Explain why some sedimentary rock layers may not always appear with youngest rock on top and older rocks below (i.e., folding, faulting).**
> **d. Research how fossils show evidence of the changing surface of the Earth.**
> **e. Propose why more recently deposited rock layers are more likely to contain fossils resembling existing species than older rock layers. (grade 8)**

Fourth graders receive an unusually precise introduction to weathering and erosion:

> **Distinguish between weathering (i.e., wearing down and breaking of rock surfaces) and erosion (i.e., the movement of materials). (grade 4)**

Unfortunately, some sections that begin strong lose rigor as they progress. High school earth systems begins with the following excellent expectations:

> **Compare the movement and results of movement along convergent, divergent, and transform plate boundaries. (high school earth systems science)**
>
> **Explain Alfred Wegener's continental drift hypothesis, his evidence, and why it was not accepted in his time. (high school earth systems science)**

But it then devolves into the vague:

> **Model the movement of materials within Earth. (high school earth systems science)**
>
> **Model the movement and interaction of plates. (high school earth systems science)**

Some content is missing—notably from the high school standards. Factors that determine climate, the study and measurement of earthquakes, and the mechanics of volcanoes are conspicuously missing. Despite a good treatment of the Big Bang theory and the evidence for it, the theoretical history of the solar system is not addressed.

Life Science

Life science starts out well in the primary grades but peters out in later years. The fourth-grade material on Utah's natural history is handled nicely. Heredity is introduced in fifth grade and microbes in sixth grade. But the seventh-grade material (where most middle school biology is commonly presented) is thin, and the standards addressing heredity do not progress much beyond the fifth-grade expectations. There is also some error: "Cite examples of organisms that reproduce sexually (e.g., rats, mosquitoes, salmon, sunflowers) and those that reproduce asexually (e.g., hydra, planaria, bacteria, fungi, cuttings from house plants)" (grade 7). But fungi reproduce sexually.

Fossils are well covered in fourth grade, and the related standards give the concept of deep time. Unfortunately, a classification unit in seventh grade is at the level of sophistication of elementary grades and avoids any mention of relatedness between organisms.

Evolution is handled well at all levels. Take, for example, this second-grade standard:

Some kinds of living things that once lived on earth have completely disappeared, although they were something like others that are alive today. (grade 2)

At the high school level, the treatment of evolution is even excellent:

Evolution is central to modern science's understanding of the living world. The basic idea of biological evolution is that Earth's present day species developed from earlier species. Evolutionary processes allow some species to survive with little or no change, some to die out altogether, and other species to change, giving rise to a greater diversity of species. … Cite evidence that supports biological evolution over time (e.g., geologic and fossil records, chemical mechanisms, DNA structural similarities, homologous and vestigial structures). (high school biology)

And there is more. A reference to the "Utah State Board of Education Position Statement on Teaching Evolution" unequivocally presents the scientific significance of biological evolution.[1]

Taken together, these strengths and drawbacks earn Utah a respectable average score of five out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Utah standards often lack specificity, especially in the physical sciences. There, standards are replete with bewildering and meaningless statements, and some outright errors. For example:

Investigate and measure the effects of increasing or decreasing the amount of energy in a physical or chemical change, and relate the kind of energy added to the motion of the particles. (grade 8)

Whatever does this mean? Or this:

Measure and graph the relationship between the states of water and changes in its temperature. (grade 8)

Similarly, when dealing with earth and space science, the document has a tendency to dance around ideas that ought to be more explicitly connected:

Relate the structure and composition of the solar system to the processes that exist in the universe.

a. Compare the elements formed in the big bang (hydrogen, helium) with elements formed through nuclear fusion in stars.

b. Relate the life cycle of stars of various masses to the relative mass of elements produced.

c. Explain the origin of the heavy elements on Earth (i.e., heavy elements were formed by fusion in ancient stars).

d. Present evidence that the process that formed Earth's heavy elements continues in stars today.

e. Compare the life cycle of the sun to the life cycle of other stars.

f. Relate the structure of the solar system to the forces acting upon it. (high school earth systems science)

A simple reference to the Hertzsprung-Russell diagram, the life cycle of supernovae, and a statement about stellar "generations" would help tremendously here.

Such complications, and the burden of excessive repetition throughout the standards, earn the Utah standards an average score of two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

[1] See the "Utah State Board of Education Position Statement on Teaching Evolution" at http://www.schools.utah.gov/CURR/science/Secondary/Evolution-Position-Statement/EvolutionPositionStatement.aspx.

SCIENCE

Vermont

GRADE	SCORES		TOTAL SCORE
C	Content and Rigor	3/7	5/10
	Clarity and Specificity	2/3	

Overview

The Vermont standards are wildly variable in terms of quality, descending from the excellent treatment of life science to the hopeless mess that passes for high school physics. To make matters worse, the document is full of typos, incomprehensible statements, and empty chatter. If Vermont schools and teachers are in fact guided by these standards, it's impossible to imagine that students will graduate having learned the essential K-12 science content they need.

Organization of the Standards

Vermont has two main standards documents: The *Framework of Standards and Learning Opportunities*, and the *Grade Expectations* that support the *Framework*.

The first document covers "science, mathematics, and technology" in seven pages, a little more than two of which are devoted to science proper. The format of the whole is a table that divides standards into five strands: inquiry, experimentation, and theory; space, time, and matter; the living world; the universe, earth, and the environment; and design and technology. Each strand is then divided into sub-strands, for which a single standard is presented for each of three grade bands: preK-5, 6-8, and 9-12. These grade-band expectations are meant to explain "how the standard can be demonstrated." For example, in grades 9-12, students are to:

> **Use Newton's laws to explain quantitatively the effects of applied forces; observe, explain, and model object motion in a plane; qualitatively investigate conservation of momentum as it relates to collisions, and investigate the mechanics of rolling motion. (grades 9-12)**

But in practice, the *Framework* serves as little more than an index to the far lengthier (122-page) *Grade Expectations*. While both documents were considered, the *Grade Expectations* was the focus of our review.

Like the *Framework*, the *Grade Expectations* document is divided first into strands, which are the same as those in the *Framework*. The strands are then divided into "enduring knowledge" themes, which are different than the *Framework's* sub-strands, and finally, into "grade-cluster expectations" (GCEs). The GCEs are presented for six grade bands: preK-K, 1-2, 3-4, 5-6, 7-8, and 9-12. The introduction to the GCE document tells us:

REPORT CARD

Content & Rigor	**2.8**
Scientific Inquiry & Methodology	5
Physical Science	4
Physics	0
Chemistry	0
Earth & Space Science	3
Life Science	5
Clarity & Specificity	**2.0**

Average numerical evaluations

Document(s) Reviewed

- *Vermont's Framework of Standards and Learning Opportunities: Science*. Fall 2000. Accessed from: http://education.vermont.gov/new/pdfdoc/pubs/framework.pdf
- *Science Grade Expectations*. Summer 2004. Accessed from: http://education.vermont.gov/new/html/pgm_curriculum/science/gle.html

The GCEs specify two-grade cluster skills and content (preK-K, 1-2, 3-4, 5-6, 7-8, and proficient at high school, and advanced at high school). Two-grade clusters will:

- **Provide more flexibility in creating local curriculum**
- **Allow for a broader time span in which developmental changes can be addressed**
- **Take into account local opportunities to learn**

But this mention serves as the only reference to the proficient/advanced distinction, and it is unclear whether it applies to introductory versus more advanced courses (i.e., as an extension of the two-grade cluster system), or to regular and honors courses, or to some other entirely different concept.

Content and Rigor

The Vermont standards are maddeningly inconsistent. Although some disciplines contain reasonably rigorous material—life science in particular—other areas of science omit critical content, fail to develop important ideas, and include surprising errors.

Scientific Inquiry and Methodology

Within the scientific inquiry strand of Vermont's GCEs, standards are grouped under six areas of "enduring knowledge": scientific questioning, predicting and hypothesizing, designing experiments, conducting experiments, reporting data and analysis, and applying results.

The expectations for students are appropriate and clearly stated. For example, in grades 1-2, a reasonable explanation is defined as one that is based on observation; by grades 3-4, it is one which accurately reflects data, and so on. Important terms such as "explanation," "prediction," and "potential bias" (to give but three examples) are highlighted so as to draw attention to their importance. The concept of fair testing is clearly defined in grades 3-4.

There are a few drawbacks. For instance, the "examples/practice items" column is left empty throughout. Some examples linking the expectations with content would no doubt be useful to teachers. In addition, from seventh grade on, students are expected to answer the "So what?" question about their investigations, but little attention overall is paid to the larger social and historical aspects of science.

Physical Science/High School Physics/High School Chemistry

While the coverage of physics and physical science is generally abysmal, Vermont presents a few bright spots. Take, for example, the following standard, which provides a clear explanation of the ideal gas law:

> **a. There exists a predictable relationship among the volume, temperature, and amount of a gas and the pressure the gas exerts.**
>
> **b. For any specified amount of a gas, the pressure that the gas exerts will increase as the temperature increases or the volume of the gas decreases. The pressure that the gas exerts will decrease as the temperature decreases or the volume of the gas increases.**
>
> **c. Gases exert pressure in all directions. (grades 7-8)**

A nice, qualitative introduction to Newton's second law appears as well, but this is somewhat marred by a circular and misleading definition of acceleration:

> **Acceleration is a relationship between the force applied to a moving object and the mass of the object (Newton's Second Law). (grades 7-8)**

Under the "energy" heading, the progression of material is questionable. Specifically, heat energy is introduced at the preK-K level (with the distinction between heat energy and temperature made in grades 1-2), and electrical energy in grades 3-4, but no mention is made of the far more concrete mechanical energy. Incredibly, the term *kinetic energy* appears nowhere in this document! And, sadly, the common silliness of throwing around the term "entropy" is seen here, including an awful attempt to define it:

> **ENTROPY = heat/temperature e.g., such as from engines, electrical wires, hot-water tanks, our bodies, stereo systems.**

Huh?

As a "science concept" repeated at several grade spans tells us, "Energy is required to transform the physical state of a substance from solid to liquid to gas, while conserving mass. Physical changes are reversible." But this is plain wrong. The melting of butter, for instance, is a physical process but when the resulting liquid is cooled one does not get butter back again.

Or consider this hodgepodge, which requires students to demonstrate their understanding of the states of matter by:

> **Investigating the interactions between atoms or molecules within a system (e.g., hydrogen bonding, van der Waals forces, fluorescent lights, stars). (grades 7-8)**

Why in the world would the standards single out two of the weakest interatomic forces—hydrogen bonding and van der Waals forces—and then jumble them together with fluorescent lights and stars? In neither of the latter two do those particular forces play a significant role, and in both of them a host of very complex interatomic interactions occur.

Such lapses are not the exception. The following is yet another risible "science concept":

> **Chemical change is a transformation of matter that results from the interaction of the molecules in a substance and a new substance results (e.g., electrophoresis of water). (grades 7-8)**

It would make a pretty exam question for the seventh and eighth graders to correct this statement!

The chemical content of physical science is no better than the physical part. Take, for example, the following expectation, which asks that students demonstrate their understanding of properties of matter by:

> **Writing formulae for compounds and developing models using electron structure (e.g., Lewis dot). (grades 9-12)**

The first part is fine, and comprises a standard part of introduction to chemical principles. But what "models" are wanted in the second? The term Lewis dot [structure] implies bonding, molecular shape, and polarity. But that critical content is conspicuously absent.

The terms ionic and covalent bonds do not appear, nor does metallic bond. Hydrogen bonding is mentioned by name, but that's all. There is no mention of chemical equilibrium, no mention of Le Châtelier's principle, and no mention of quantum or Bohr atomic models.

Finally, nothing in the standards document is suitable for the conventional high school course in physics or chemistry—a major failing.

Earth and Space Science

Earth and space science fares somewhat better, but not much. Occasional flashes of detailed critical content appear, but overall, serious gaps persist. Significant in their absence are such important topics as rocks and minerals, the workings of volcanoes and earthquakes, the greenhouse effect, and the solar cycle.

Furthermore, while there is an attempt to build on content from grade to grade, sometimes the addition at each step is little more than trivial. Take, for example, the following standards for grades 3-8:

> **Students demonstrate their understanding of Processes and Change over Time within Earth Systems by…**
>
> - **Describing water as it changes into vapor in the air and reappears as a liquid when it is cooled. (grades 3-4)**
> - **Diagramming, labeling, and explaining the process of the water cycle (e.g., evaporation, precipitation, run-off). (grades 5-6)**
> - **Diagramming, labeling, and explaining the process of the water cycle (precipitation, evaporation, condensation, runoff, ground water, transpiration). (grades 7-8)**

This grade-to-grade "progress" is little more than reiteration of the same ideas in different words.

Worse still, some items are written so broadly that they present virtually no meaningful content whatsoever. Consider the following examples:

> **Identify and record patterns and forces that shape the earth (e.g., geological, atmospheric). (grades K-4)**

> **Identify, record, and model evidence of change over time (e.g., earth's history: biological, geological). (grades 5-8)**

> **Explain the emergence of modern views of the universe (past, present, and future scientific theories). (grades 9-12)**

In addition to being virtually useless to teachers and curriculum developers, we are bemused by the requirement that high school students explain cosmological views of the future as well as those of the past and the present.

Life Science

While life science suffers from some errors and omissions (discussed below), it generally receives the best content coverage of any of the sciences. Overall, the content and flow of this section is impressive. Clearly, the writers did not just download boilerplate from other sources. For example, in the first unit of fifth- and sixth-grade life science, cells are introduced by noting that they have the same survival needs as organisms and that they differentiate. Too often, this key point is not made, even in high school. There is also a good treatment of physiology in these grades, even introducing white blood cells, and a good unit on embryos.

All continues to go well at the high school level. We read, "All body cells have identical genetic information, but its expression may be very different from one cell to another due to the instructions given to different types of cells" (grades 9-12). There is a major unit on embryo development and a sophisticated consideration of human physiology and disease.

Evolution is treated adequately but far from thoroughly. In the beginning grades, we read of "things that no longer live on earth (wooly mammoth)" (grades 1-2). In seventh and eighth grades, there is a fairly minimal consideration of the concepts, but the core ideas are there. At the high school level, the core ideas are again there, but compared with, say, the in-depth coverage of physiology and genetics, the treatment is skeletal and confined to one box.

As mentioned above, the treatment of life science does present some errors. For instance, a preK-K standard begins with the following:

> **The human body is unique in its heredity, body systems, and development, and can be affected by the environment. (preK-K)**

This is repeated in third and fourth grades. Yet the human body is NOT unique in its heredity, and while one of its body systems (the brain) has important (to us) unique features such as the capacity to learn symbolic language, the important point is that the human body is overwhelmingly like other mammals.

Reflecting its flashes of excellence amidst mediocrity, Vermont earns a three out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The Vermont documents are marred by many typos and much tangled phraseology, and often the grade-to-grade development is inadequate. As noted above, the specificity of subject-matter treatment varies widely from subject to subject.

Logical and pedagogical inconsistencies abound. In physical science, what students learn in grades 5-6 is contradicted in grades 7-8:

> **All substances have a unique density that depends on the volume (amount of space) that the substance is packed into. (grades 5-6)**
>
> **Changing the temperature of materials will change the density of the material. (grades 7-8)**

In physics, motion and force are presented in two separate sections, in that order. But dynamics (including Newton's second law) is subsumed under motion, which leads to confusion. It would have been much better to divide the subject the logical way, into kinematics and dynamics.

Taken together, the strengths marginally outweigh the weaknesses, earning Vermont an average score of two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Virginia

GRADE	SCORES		TOTAL SCORE
A-	Content and Rigor	6/7	9/10
	Clarity and Specificity	3/3	

REPORT CARD

Content & Rigor	**5.8**
Scientific Inquiry & Methodology	2
Physical Science	7
Physics	5
Chemistry	7
Earth & Space Science	7
Life Science	7
Clarity & Specificity	**3.0**

Average numerical evaluations

Overview

The Old Dominion's science standards are among the few that we would cheerfully recommend as models for other states (and for drafters of "common" standards for this field). They are thorough and rigorous, particularly in the areas of mathematical applications and evolution, and they clearly provide a solid foundation for a rigorous K-12 science curriculum.

Organization of the Standards

Virginia's K-6 standards are divided first into seven strands (scientific investigation, reasoning, and logic; force, motion, and energy; matter; life processes; interrelationships in earth/space systems; earth patterns, cycles, and change; and earth resources), which are common across all grades. For each strand, the state presents grade-specific standards. Finally, a list of "key concepts" that students must learn further clarifies the standards. For instance, under the "life processes" strand in fourth grade, students "will investigate and understand basic plant anatomy and life processes," with key concepts that include photosynthesis and the structures of typical plants.

The standards for grades 7-12 are presented similarly, except that they are organized by course rather than by grade: for life science, physical science, earth science, biology, chemistry, and physics. A "test blueprint" provided along with the standards indicates that students are to be assessed in life science and physical science by eighth grade. Thus, in this review, we refer to all other course standards as high school standards.

In addition, Virginia provides a separate curriculum framework that further clarifies "the minimum content that all teachers should teach and all students should learn."

Content and Rigor

The content material in the Virginia standards is well written and well organized by a group of authors whose knowledge of science is clearly substantial. The rigorous material is almost always grade-level appropriate, and it is a pleasure to see mathematical expressions used where needed. The word "calculate" appears regularly in the documents, a sure sign that the standards are on the right track.

Document(s) Reviewed

- *Virginia Science Standards of Learning: Standards and Curriculum Framework.* January 2010. Accessed from: http://www.doe.virginia.gov/testing/sol/standards_docs/science/review.shtml

Scientific Inquiry and Methodology

Virginia's inquiry and process material, contained under the strand of "scientific investigation, reasoning, and logic," is perhaps the standards' lowest point. This material is presented with no explicit connection to Virginia's content standards or with any examples of how they may work into classroom activities. Further, Old Dominion's inquiry standards, while appropriate, are excessively brief and are often repetitious or vague. This leaves a disjunction between the aspirations of the writers and what will be taught in classrooms. What's more, for grades five through twelve, the writers state:

> **The nature of science includes the concepts that scientific explanations…are subject to refinement and change with the addition of new scientific evidence; … The nature of science includes the concept that science can provide explanations about nature…but cannot be used to answer all questions. (grades 5-12)**

Yet, the history of science and the philosophical issue of the limits of inquiry are never mentioned in the grade-specific expectations.

Physical Science

The physical sciences are presented very well, especially in Kindergarten through sixth grade. The treatment of simple machines in third grade is elegant. Simple ideas of electricity and magnetism are introduced in fourth grade, with even a bit of electromagnetic interaction. Waves, sound, and light are nicely introduced in fifth grade; the instructor is even provided with a clear picture of a longitudinal wave. In sixth grade, physical science emphasizes energy and the atomic structure of matter, leading into some significant elements of chemistry. Energy is treated properly, if not rigorously enough. Laudably, the standards distinguish between kinetic and potential energy in a way that avoids confusion with the distinction between such types of potential energy as chemical, electrical, or mechanical.

High School Physics

The high school physics standards cover all of the essential content, and much of it quite well. For example, mechanics (notably kinematics) is handled well—as are waves, in all their manifestations (general wave theory, sound, and light).

There are a few drawbacks, however. While the coverage is comprehensive, the standards rush over some key concepts: Dynamics and kinematics are scrambled together, and the discussions of energy and Newton's laws are disappointingly brief.

Basic electricity is covered, but as is too often the case in high school physics standards, Ampère's and Faraday's laws are slighted; they are mentioned only qualitatively and in passing. Here is a lost opportunity to convey a real understanding of electromagnetic radiation.

All of modern physics (most of physics since 1900 or so) is covered in a single, rather ambitious standard. While this format could well frame recent additions to physics thought, instead it simply abridges the list of student expectations, boiling them down to this:

> **Explain that the motion of objects traveling near or approaching the speed of light does not follow Newtonian mechanics but must be treated within the theory of relativity.**
>
> **Describe the relationship between the Big Bang theory timeline and particle physics.**
>
> **Describe the structure of the atomic nucleus, including quarks. (high school physics)**

The first of these statements is negative and gives no hint of why one must do this or what supplements or supplants Newton's laws. The second is so broad as to cover a library of physics research. The third is a subject for a fat textbook. If all the salient areas of physics were as well covered as mechanics (especially kinematics) and waves, Virginia's standards would move from good to excellent.

High School Chemistry

Virginia's chemistry standards are both clear and rigorous. They deftly maneuver through difficult concepts—especially through the curriculum framework. Some examples:

> **Electronegativity is the measure of the attraction of an atom for electrons in a bond. Electronegativity increases from left to right within a period and decreases from top to bottom within a group.**
>
> **Name binary covalent/molecular compounds.**
>
> **Name binary ionic compounds (using the Roman numeral system where appropriate). (high school chemistry)**

A long and rigorous standard both requires students to calculate stoichiometric values and explains the relationship between various units:

> **Perform stoichiometric calculations involving the following relationships: mole-mole; mass-mass; mole-mass; mass-volume; mole-volume; volume-volume; mole-particle; mass-particle; and volume-particle. (high school chemistry)**

A bit of nit-picking, though: This standard could have been made even stronger if the writers had added "volume of a gas at STP or at specified conditions" whenever the volume of a gas is involved in a question.

Further examples illustrate the breadth of Virginia's chemistry standards:

> **Perform titrations in a laboratory setting using indicators.**
>
> **Calculate energy changes, using molar heat of fusion and molar heat of vaporization…and specific heat capacity.**
>
> **Perform calculations involving the molarity of a solution, including dilutions. (high school chemistry)**

Collectively, these standards will provide students with excellent preparation for college-level chemistry.

Earth and Space Science

The content coverage in earth and space science is also good, if not quite on par with chemistry. Plate tectonics and weather systems are particularly well covered.

The content provided in the curriculum framework adds significant value as well. For example, the fifth-grade standard, "Describe the structure of Earth in terms of its major layers—crust, mantle, and outer core and inner core—and how Earth's interior affects the surface," is explained further with the following:

> **Scientific evidence indicates that Earth is composed of four concentric layers—crust, mantle, outer core, and inner core—each with its own distinct characteristics. The outer two layers are composed primarily of rocky material. The innermost layers are composed mostly of iron and nickel. Pressure and temperature increase with depth beneath the surface. (grade 5)**

There is also solid development of the standards from grade to grade. A follow-up to the fifth-grade example above states: "Earth consists of a solid, mostly iron inner core; a liquid, mostly iron outer core; a crystalline but largely plastic mantle; and a rocky, brittle crust" (high school earth science).

Virginia's standards do fall slightly short in a few places. The mechanics and details of exciting phenomena like earthquakes, volcanoes, and tsunamis are slighted, for example. These phenomena are often in the news, and they can pose hazards for which students even in low-risk areas ought to be prepared (as the fall 2011 seismic events in Virginia underscore). No matter the locale, practical knowledge has its relevance.

Further, some important content normally seen in earlier grades is postponed to high school, although younger students would enjoy subjects such as mineral identification.

Life Science

While most of the Virginia standards are strong, the life sciences are the best of the bunch. For example, there is an entire second-grade unit on the white-tailed deer. A similarly well-developed fourth-grade standard includes an excellent explanation of the fact that plant seeds contain embryos.

Fifth-grade students learn about cells and their organelles—matters usually postponed to junior-high grades. The materials for seventh and eighth grades include good coverage of physiology, full coverage of genetics and heredity, including DNA and chromosomes, and excellent treatment of evolution. Many high school biology courses barely match what is done here, yet the presentation is all fully within the grasp of a middle-school student.

The high school materials could likely be used for an Advanced Placement course but are certainly appropriate for the regular course offering, given the excellent background established in middle school. Biochemistry concepts are sophisticated and well explained; genetics and molecular biology are outstanding. The unit on physiological systems is exceptional, and the treatment of ecology and evolution is well above average.

Indeed, Virginia's handling of evolution deserves special mention. The state incorporates evolution into the standards at an early grade:

> **Fossils provide information about living systems that were on Earth years ago. (grade 2)**

The standards go further to present interesting (and relevant) contextual background on fossils:

> **Virginia's state fossil, Chesapecten jeffersonius, is a large extinct species of scallop that dates to approximately 4.5 million years ago. It was the first fossil ever described in North America and is named after Thomas Jefferson, one of our founding fathers, and an amateur paleontologist. (grade 2)**

Seventh and eighth grades also offer an extensive coverage of evolution equivalent to or surpassing most states' high school offerings, and as noted above, the high school treatment is likewise outstanding.

With so many strengths, especially in chemistry and life sciences, Virginia receives a solid score of six out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

Navigating the Virginia standards—as well as its supplemental curriculum framework—is a pleasure. Material is cleanly presented and easily found. The *Framework's* "essential understandings," which provide background material for teachers, are beautifully written and would be useful to any teacher, especially the novice. For example, heat and temperature are often conflated in standards; Virginia's "essential understanding" on the topic ensures clarity of content:

> **Heat and temperature are not the same thing. Heat is the transfer of thermal energy between substances of different temperature. As thermal energy is added, the temperature of a substance increases.**
>
> **Temperature is a measure of the average kinetic energy of the molecules of a substance. Increased temperature means greater average kinetic energy of the molecules in the substance being measured.…The temperature of absolute zero (–273°C/0 K) is the theoretical point at which molecular motion stops. (grades 7-8 physical science)**

(As everything else is covered extremely well, we can forgive the neglect of the zero-point motion that is characteristic of all matter at 0 K, and of the fact that the temperature of a substance does not increase during phase change.)

Unfortunately, essential equations, including Newton's law of universal gravitation and Coulomb's law, are attached to less specific and less satisfactory statements such as "describe the attractive or repulsive forces between objects relative to their forces and distance between them (Coulomb's Law)" and "describe the attraction of particles (Newton's Law of Universal Gravitation)." The Old Dominion would be wise to reincorporate them into the standards.

Virginia's successful effort does not involve magic or gimmickry. Every state could (and should) emulate these standards—if not literally, then at least as a model of serious thinking about science curricula. The score of three out of three for clarity and specificity is well earned. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Washington

GRADE	SCORES		TOTAL SCORE
C	Content and Rigor	3/7	6/10
	Clarity and Specificity	3/3	

REPORT CARD

Content & Rigor	**3.3**
Scientific Inquiry & Methodology	5
Physical Science	3
Physics	0
Chemistry	0
Earth & Space Science	5
Life Science	7
Clarity & Specificity	**2.9**

Average numerical evaluations

Overview

Washington's science standards are a study in extremes. In some areas—notably life science—the content is clearly presented, thorough, and free from errors. By contrast, other disciplines suffer from glaring omissions of important content. Taken together, Washington's standards earn an average grade, but this average masks wild variability in quality.

Organization of the Standards

The Washington science standards are divided first into four "Essential Academic Learning Responsibilities" (EALRs): systems, inquiry, application, and the domains of science. Only the last of these is devoted to science content, and it is divided into three domains: life science, physical science, and earth and space science.

Each EALR is then divided into a series of "big ideas." (There are nine big ideas in the domains of science EALR.) Then the state provides a core content summary that broadly describes what students should know and be able to do within each big idea.

Finally, the state provides content standards and performance expectations for each of five grade bands: K-1, 2-3, 4-5, 6-8, and 9-12. The content standards describe what students should know, and the performance expectation describes what they should be able to do. For instance, one content standard and related performance expectation for grades K-1 explains:

	Content Standard	**Performance Expectation**
	Students know that:	***Students are expected to:***
K-1 ES2A	**Some objects occur in nature; others have been designed and processed by people.**	**Sort objects into two groups: *natural* and *human-made*.**

Content and Rigor

The Washington standards hit glorious peaks—see life science in particular—and equally deep valleys.

Document(s) Reviewed

▸ *Washington State K-12 Science Learning Standards*. 2009. Accessed from: http://www.k12.wa.us/Science/Standards.aspx

High school physics and chemistry are essentially absent, but earth and space science offers some redemption.

Scientific Inquiry and Methodology

The Washington process standards cover most of the content that students need to learn, though they do so in a way that's neither particularly inspired nor particularly offensive. Fourth- and fifth-grade students, for example, are told that:

> **Scientists plan and conduct different kinds of *investigations*, depending on the *questions* they are trying to answer. Types of *investigations* include systematic *observations* and descriptions, *field studies*, *models*, and *open-ended explorations* as well as *controlled experiments*. (grades 4-5)**

Given a pre-selected research question, the related performance expectation asks students to:

> **…plan an appropriate *investigation*, which may include systematic *observations*, *field studies*, *models*, *open-ended explorations*, or *controlled experiments*.**
>
> **Work collaboratively with other students to carry out a *controlled experiment*, selecting appropriate *tools* and demonstrating safe and careful use of equipment. (grades 4-5)**

Like most of the inquiry standards, these are generally clear and grade-appropriate, and the content progresses well through the grades.

The standards do have a few flaws, however. As in many other states, some expectations descend into platitudes. For instance, the claim that people "in all cultures have made and continue to make contributions to society through science and technology" is overly broad—and is not entirely true. And the history of science receives no mention.

Physical Science/High School Physics/High School Chemistry

In general, the physical science standards are succinctly and correctly stated, in proper logical order. For instance, in the grade band covering second and third grades we find:

> ***Motion* can be *described* as a change in position over a period of time.**
>
> **There is always a *force* involved when something starts moving or changes its *speed* or direction of *motion*.**
>
> **A greater *force* can make an object move faster and farther.**
>
> **The relative strength of two *forces* can be *compared* by observing the difference in how they move a *common* object. (grades 2-3)**

Now that is good physics—and quite a lot of it—insightfully stated so that a second or third grader can understand it. Similarly challenging but reasonable expectations of students continue in higher grades.

Quantitative treatments of mechanics and other subfields of physics begin modestly in sixth through eighth grades, and in high school, mathematical statements are used wherever necessary.

The high school physical science material is excellent at a relatively low level, with first-rate information for planning a ninth-grade course. Unfortunately, there are no higher-level standards that could inform a rigorous high school physics course. And even for a physical science course, much essential material is missing. For instance, thermodynamics is slighted, as is optics.

Chemistry is covered only within the context of physical science, as there is no separate course devoted to high school chemistry. No doubt because it isn't treated separately, there are huge blind spots. For example, ionic and covalent bonds are mentioned—but no others. Nothing about molarity appears, nor any discussion of the prediction of chemical reactions between elements. The list of omissions goes on and on.

Earth and Space Science

Some subjects in this category are covered quite well, especially those related to space. For example, stars and galaxies, motion of planets, the Milky Way, and the solar system are all well covered. Standards addressing earth layers are equally strong, as demonstrated by the following standard:

> **The solid Earth is composed of a relatively thin crust, a dense metallic core, and a layer called the mantle between the crust and core that is very hot and partially melted. (grades 6-8)**

By contrast, other topics, many dealing with solid-earth processes, are incomplete or ignored. For example, there is scant mention of minerals (except when they are dissolved) and the mechanics of earthquakes and volcanoes. While plate tectonics gets some mention—especially in the elementary grades—the evidence supporting the theory is missing. There are also several gross errors or oversimplifications in the standards. Take, for example, the following performance expectation:

> ***Explain how*** **the age of landforms can be estimated by studying the number and thickness of rock layers, as well as *fossils* found within rock layers. (grades 6-8)**

For starters, the standard should ask students to explain the age of rocks, not of landforms. Furthermore, the phrase "the number and thickness of rock layers" is so oversimplified, it's simply wrong.

Similarly, the following standard oversimplifies the process of weathering:

> ***Weathering*** **is the breaking down of rock into pebbles and sand caused by physical processes such as heating, cooling, and pressure, and chemical processes such as acid rain. (grades 4-5)**

In fact, it's not the heating and cooling of rocks that is the major cause of physical weathering but rather the presence of *water* during such temperature shifts, an important distinction worth mentioning. And the products of weathering consist of more than just pebbles and sand; they also include clay and dissolved minerals.

There are some brighter spots. Fossils are thoroughly covered, and much time is spent explaining stars, galaxies, and planets and their motion. The notion of deep time is squarely addressed. Washington even produces some "wow" moments; its version of the ubiquitous "constructive and destructive forces" idea is more useful than most, as it specifically addresses uplift, weathering, and erosion without falling into the vague:

> ***Explain how*** **a given landform (e.g., mountain) has been shaped by processes that build up structures (e.g., uplift) and by processes that break down and carry away material (e.g., *weathering* and *erosion*). (grades 6-8)**

And the following general statement about plate tectonics is unique in mentioning the approximate rate of the motion:

> **The *crust* is composed of huge *crustal plates* on the scale of continents and oceans which move centimeters per year, pushed by *convection* in the upper *mantle*, causing earthquakes, volcanoes, and mountains. (grades 6-8)**

Representative of Washington's standards, this statement is rigorous but stumbles in that it opts for the general term "crust" instead of the correct "lithosphere."

Life Science

By far the strongest of the Washington standards are those for life science, which are thorough, well-explained, and grade-appropriate. For instance, Kindergartners and first-grade students are asked to:

> ***Compare*** **how different animals use the same body parts for different purposes (e.g., humans use their tongues to taste, while snakes use their tongues to smell). (grades K-1)**

And the physiology coverage through eighth grade is equally strong. (One important flaw is the complete lack of physiology coverage in high school.)

Evolution is covered well, too. The big idea devoted to biological evolution emerges in Kindergarten and first grade and continues from there, with a clear progression of content and rigor through the successive grades. In addition, there is significant coverage of fossils by fourth and fifth grades.

The standards also make the importance of evolution clear, specifically stating:

> **The scientific *theory* of *evolution* underlies the study of biology and explains both the *diversity* of life on Earth and similarities of all *organisms* at the chemical, cellular, and molecular level. *Evolution* is supported by multiple forms of scientific *evidence*. …*Evidence* for *evolution* includes similarities among anatomical and cell structures, and *patterns* of development make it possible to *infer* degree of relatedness among *organisms*. (grades 6-8)**

The strong coverage of evolution continues in high school, as evidenced by the following:

> **Both the fossil record and analyses of DNA have made it possible to better understand the causes of variability and to determine how the many species alive today are related. Evolution is the major framework that explains the amazing diversity of life on our planet and guides the work of the life sciences. (grades 9-12)**

In addition, common ancestry, deep time, and other essential concepts are addressed well.

Without the total failure of physics and the near-total failure of chemistry, the Washington standards would fare reasonably well in content and rigor. Unfortunately, these major stumbles overwhelm the standards' glimmers of excellence and drag the state's score down to a three out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

At their best, the Washington standards contain statements that express critical content in crystal-clear prose. For instance, in the physical science material for grades six through eight we have:

> **Substances have *characteristic intrinsic properties* such as *density*, *solubility*, *boiling point*, and *melting point*, all of which are independent of the amount of the sample.**
>
> ***Students are expected to:***
>
> **Use *characteristic intrinsic properties* such as *density*, *boiling point*, and *melting point* to identify an unknown substance. (grades 6-8)**

Much of the rest of the document is similarly lucid and specific. But it is not perfect. As happens frequently in many states, an excellent set of standards is kneecapped by a truly dumb glossary. Consider some of the worst offenders in the Washington document:

> **Apply: The skill of selecting and using information in new situations or problems.**

As in "A good student acquires many applies"?

> **Chemical properties: Any of a material's properties, such as color, pH, or ability to react with other chemicals, that becomes evident during a chemical reaction.**

Of course, color is emphatically not a chemical property. And, as for pH, this implies that the chemical properties of HCl depend on its concentration, which is not true.

Sadly, these are the rule in the glossary, not the exception.

Omitting the silly glossary, however, the presentation and organization of the standards are generally top-notch. As such, they earn a solid three out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

West Virginia

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	3/7	4/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**3.2**
Scientific Inquiry & Methodology	5
Physical Science	4
Physics	2
Chemistry	4
Earth & Space Science	1
Life Science	3
Clarity & Specificity	**1.3**

Average numerical evaluations

Overview

The West Virginia science standards are a confusing and unsatisfactory hodgepodge. The mediocre treatment at the K-8 level descends into a bewilderment of ill-defined and overlapping courses at the high school level. Making matters worse, the rigor of the standards is wildly inconsistent, both within and across grades.

Organization of the Standards

West Virginia presents content standards for each grade, K-8, and for thirteen courses at the high school level, including: Physics I, Conceptual Physics, Chemistry I, Biology I, Earth Science, and two amorphous grade-specific courses (Ninth Grade Science and Tenth Grade Science). Process standards are presented by grade band, for grades K-4, 5-7, 8, and 9-12. The content is divided first into three "standards" (commonly thought of as "strands"): nature of science, content of science, and application of science. For each standard, the state provides several bullets that broadly describe what students should know and be able to do. For instance, under "content of science," the state indicates that, by the end of the year, fifth graders will:

> **Demonstrate knowledge, understanding, and applications of scientific facts, concepts, principles, theories, and models as delineated in the objectives.**
>
> **Demonstrate an understanding of the interrelationships among physics, chemistry, biology, and the earth and space sciences.**
>
> **Apply knowledge, understanding, and skills of science subject matter/concepts to daily life experiences. (grade 5)**

Finally, the state provides grade-specific learning objectives.

In addition, West Virginia offers a set of performance descriptors for each grade-specific learning objective that describe student mastery of the standard across five levels of achievement: novice, partial mastery, mastery, above mastery, and distinguished. These are presumably linked to state assessments.

Document(s) Reviewed

- *Twenty-First Century K-8 Science Content Standards and Objectives for West Virginia Schools*. 2009. Accessed from: http://wvde.state.wv.us/policies/p2520.3.pdf
- *Twenty-First Century 9-12 Science Content Standards and Objectives for West Virginia Schools*. 2010. Accessed from: http://wvde.state.wv.us/policies/p2520.35.pdf

Content and Rigor

Inconsistency and confusion dog the West Virginia standards. Content ranges from middling (physical science and chemistry) to poor (earth and space science). The sections that address "applications of science" harp endlessly on models and systems. Meanwhile, the presence of more than a few unrealistic goals for grade-level knowledge suggests that too little thought went into creating the standards.

Scientific Inquiry and Methodology

West Virginia's process standards are included within the "nature of science" standard which, according to the state, explores three topics: (1) science as a human endeavor, (2) historical and current discoveries, and (3) the history and nature of science. Oddly, the state suggests that 50 percent of instructional time be devoted to "active inquiry through investigations and hands-on activities," something that would be difficult to do for two thirds of the topics covered.

As is often the case with inquiry standards, the writers have tried to present process goals as measurable outcomes, leading to some poorly worded and bizarre standards. For instance, in Kindergarten, students will "demonstrate curiosity." What that means in practice is difficult to know.

In addition, process standards are presented by grade band, rather than by grade. Unfortunately, by grouping the standards this way, the rigor of the expectations is often inappropriate. For instance, it would be difficult for Kindergartners to "demonstrate an understanding of the history and nature of science." Moreover, the standards give no indication as to how these expectations are meant to increase in rigor from grade to grade.

Physical Science

West Virginia's physical science standards are rarely grade appropriate, oscillating between asking too much and too little of students. In first grade, for example, they are expected to "predict and investigate the buoyancy of objects in water," a tall order considering that this requires an understanding of ratios, which youngsters won't learn until much later. First graders also are asked to "create a plant or animal"—an impossibility at present, and likely to be too difficult for the foreseeable future.

In eighth grade, students are expected to know how to use the periodic table, the various models of the atom (Crookes, Thompson, Bohr, etc.), the factors that affect chemical reactions, and the Doppler Effect. Again, this is asking something that students at this level aren't likely to be able to achieve with any level of depth or rigor.

On the other hand, first graders are asked to "classify objects as living or non-living," when they could certainly do more rigorous work. And seventh graders are asked to "explain how changing latitude affects climate"—a task more suitable for younger students.

Many statements are carelessly written—or patently wrong. For example, third graders are asked to "relate changes in states of matter to changes in temperature." These are two unrelated concepts: During state changes, there are only changes in heat content, not in temperature.

Other statements reflect haphazard organization. In seventh grade, for example, students are asked to "perform experiments to identify substances and explain chemical reactions." Yet the discussion on atoms is not introduced until the following academic year.

Errors often creep in, too. In second grade, for instance, students are asked to identify which colors best conduct heat, when certainly the standards must intend to ask which colors best *absorb* heat.

High School Physics

The entire subject of physics is covered in eighteen one-sentence statements, making it impossible to cover all important topics. Worse, the statements are badly balanced, slighting or ignoring important issues (such as mechanics and thermodynamics) while overemphasizing others (particularly fluid mechanics). Paradoxically, Conceptual Physics—a remedial physics course outlined in the state standards—does a marginally better job of covering the most important material.

High School Chemistry

West Virginia high school students are offered the option of three different chemistry courses: Chemistry I, Chemistry II, and a lower-level Conceptual Chemistry course. Unfortunately, the chemistry content doesn't build coherently from grade to grade. Chemistry I is missing many important topics that are included in the lower-level Conceptual Chemistry course, including: enthalpy; kinetic theory; polar and nonpolar bonding; and proper definitions of pH, oxidation, and reduction. Also missing from Chemistry I are fundamental topics like VSEPR theory and Lewis dot techniques, and Hess's law. These topics are included in Chemistry II. Unfortunately, it's reasonable to assume that relatively few students will take advanced chemistry and that far too many students will graduate from high school without being exposed to some critical content.

Earth and Space Science

The inconsistency of rigor that plagues the West Virginia standards is evident in the earth and space science standards as well. For example, sixth graders are asked to "compare and contrast continental drift hypothesis to the plate tectonic theory," a highly sophisticated and complex expectation for a twelve-year-old.

In addition, the performance indicators, which are meant to elucidate standards, are often just tangentially related to the standards they're meant to clarify. For example, a series of sixth-grade performance indicators asks students to do the following:

- **Distinguished: research current evidence in plate tectonics theory.**
- **Above Mastery: explain how geologic evidence is used to support the plate tectonics theory.**
- **Mastery: trace the history of the plate tectonics theory and associate life forms to geologic eras.**
- **Partial Mastery: describe plate tectonics theory and recognize that life forms change with geologic eras.**
- **Novice: label plates and recognize that life forms change over time. (grade 6)**

Unfortunately, the only grade-specific objectives to which these performance indicators are linked make no mention of plate tectonics. And although plate tectonics is mentioned in a different set of performance indicators, those don't clarify the prerequisite content students must master to prepare for these more advanced topics.

What's more, these indicators require an understanding of the relationship between life forms and plate tectonics to demonstrate "partial mastery"—yet the connections between plate tectonics and life forms is complicated. Recognizing how life forms change over time is a separate line of study and not a throw-away "partial mastery" concept. Further, it is puzzling that only "above mastery" students are expected to understand the basic geological evidence for plate tectonics, a fundamental concept that should be expected of all students, while the "mastery" level demands more knowledge and a higher level of analysis.

The ninth-grade Earth Science course contains a modest amount of astronomy and geology, which normally are contained within a separate earth and space science sequence. Both are handled with sweeping generalities, as in this standard:

> **Analyze several origin theories of the solar system and universe and use them to explain the celestial bodies and their movements. (high school earth science)**

Galaxies are not mentioned.

Life Science

Throughout the West Virginia standards, much text is devoted to useless descriptors of progress and inquiry, leaving the treatment of content marginal at best. Middle school in particular offers little sense as to what will be taught. Instead, vague dicta reign:

> **Identify the structures of living organisms and explain their functions. (grade 5)**
>
> **Classify living organisms according to their structures and functions. (grade 6)**
>
> **Discuss how living cells obtain the essentials of life through chemical reactions of fermentation, respiration and photosynthesis. (grade 8)**

For the content areas that are addressed, how teachers are to pursue them is largely left unstated. Students in fifth grade are asked to "compare and contrast how the different characteristics of plants and animals help them to survive in different niches and environments including adaptations, natural selection, and extinction," yet none of the key terms is explained. Again, in seventh grade, students are told to "explain how an organism's behavior response is a combination of heredity and the environment." But heredity has not been discussed, severely crippling the exercise.

Overall, evolutionary concepts prove hard to find. Indeed, neither the phrases nor the substance of evolution, variation, natural selection, or common ancestry appear anywhere in Kindergarten through eighth grade. Moreover, the performance descriptors in the standards fail to mention natural selection, implying that it will not be tested.

The course titled Tenth Grade Science offers a list of fifteen topics, in which students finally are introduced to DNA. But it's a strange meeting, because students are asked to "apply DNA analysis to current societal and technological issues (e.g., DNA's role in protein synthesis, heredity, cell division, or cellular functions)," rather than simply learning about these matters directly.

West Virginia also appears to flirt with creationism in the upper grades. Tenth-grade students must "construct a scientific explanation for variation in the species and common ancestors using fossil records, homologous features and selective pressures" and are asked to "compare and contrast theories for the development, diversity and/or extinction of a species (e.g., natural selection, Lamarckism, or catastrophism)"—where catastrophism could include events such as Noah's Flood. So, although creationism is not explicitly mentioned, one infers an invitation to the lamentable "teach the controversy" creationist rhetoric regarding evolution.

The overall mark for content and rigor is a sub-par three out of seven (see Appendix A: Methods, Criteria, and Grading Metric), which would be lower save for slightly better handling of physical science and chemistry.

Clarity and Specificity

West Virginia's learning objectives are repetitive and disjointed. Far too much content is repeated nearly verbatim across grade levels, as in the following, which appears at every level from Kindergarten through fourth grade:

> **Demonstrate an understanding of the history and nature of science as a human endeavor encompassing the contributions of diverse cultures, scientists, and careers. (grades K-4)**

This standard is broad to the point of uselessness. Standards under the "application of science" banner are even more repetitious, harping about models and systems, grade after grade.

Worse, the standards themselves show a lack of flow and integration across grade levels. For example, mechanics objectives within the high school physics standards are scattered across the list of objectives, instead of being presented together in a coherent sequence.

Finally, the content itself is not organized by discipline, theme, or any other apparent structure. Instead, standards are all lumped together in a series of half-sentence arm-waves that rarely get specific.

The performance descriptors are complicated and breathless rubrics from which substantive details only rarely emerge. Often the middle tiers are the most sensible expectations, while the "distinguished" category describes levels of performance more properly expected of competent adult scientists. Some of the verbs employed describe lesson plans rather than measurable outcomes: observe, listen, study, explore, investigate.

Taken together, these drawbacks earn the science standards an average score of one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Wisconsin

GRADE	SCORES		TOTAL SCORE
F	Content and Rigor	0/7	0/10
	Clarity and Specificity	0/3	

REPORT CARD

Content & Rigor	**0.2**
Scientific Inquiry & Methodology	0
Physical Science	0
Physics	0
Chemistry	0
Earth & Space Science	0
Life Science	1
Clarity & Specificity	**0.0**

Average numerical evaluations

Overview

Wisconsin's science standards—unchanged since 1998, in spite of much earlier criticism, ours included—are simply worthless. No real content exists to evaluate. In lieu of content, the "authors" have passed the buck by merely citing unelaborated references to the now outdated National Science Education Standards (NSES). Rather than using the NSES as building blocks for a comprehensive set of science standards, however, Wisconsin has used them as an escape hatch to avoid hard work and careful thought.

Organization of the Standards

Wisconsin divides its science expectations into eight strands: science connections, nature of science, science inquiry, physical science, earth and space science, life and environmental science, science applications, and science in personal and social perspectives. For each strand, the state provides a one-sentence content standard and a rationale that notes its importance. For instance, the physical science standard requires that:

> **Students in Wisconsin will demonstrate an understanding of the physical and chemical properties of matter, the forms and properties of energy, and the ways in which matter and energy interact.**

And the rationale explains:

> **Knowledge of the physical and chemical properties of matter and energy is basic to an understanding of the earth and space, life and environmental, and physical sciences. The properties of matter can be explained in terms of the atomic structure of matter. Chemical reactions can be explained and predicted in terms of the atomic structure of matter. Natural events are the result of interactions of matter and energy. When students understand how matter and energy interact, they can explain and predict chemical and physical changes that occur around them.**

Finally, performance standards are presented for fourth, eighth, and twelfth grades. Wisconsin delineates no content expectations for any other grades.

Document(s) Reviewed[1]

- *Wisconsin's Model Academic Standards for Science*. 1998. Accessed from: http://www.dpi.state.wi.us/standards/sciintro.html

[1] Fordham's 2005 evaluation also reviewed Wisconsin's 1998 content-standards document. Since 2005, we have updated and improved the evaluation criteria used to judge the standards. (See Appendix A for a complete explanation of criteria used in this review.) Even with these changes, Wisconsin's science standards still earn an F. The complete 2005 review can be found here: http://www.edexcellence.net/publications-issues/publications/sosscience05.html.

Content and Rigor

Any educator who might hope to create a curriculum from the Wisconsin science material would be stranded in a dismal, content-free desert. True standards are provided for just three grades, and the content provided for those grades is almost nonexistent.

Scientific Inquiry and Methodology

Like most of the content standards, the standards for inquiry and methodology are devoid of any real substance. For example, a fourth-grade standard tells students, "When studying a science-related problem, decide what changes over time are occurring or have occurred." What this is meant to signify—or what skills are intended for mastery—is impossible to know.

Similarly, in twelfth grade, students are asked to "apply the underlying themes of science to develop defensible visions of the future." Again, what this means for curriculum development, instruction, or assessment is anyone's guess. Woefully, such examples are the rule, not the exception.

Historical and social aspects of science (beyond technological concerns) are given the slightest of mentions. This may be a mercy, given how process and inquiry have been covered.

All Content Areas

It's virtually impossible to evaluate the content of the Wisconsin science standards because almost none is presented. Of the eight strands, only three—physical science, earth and space science, and life and environmental science—address bona fide scientific content. (The other five are devoted to process and inquiry.) Moreover, all the content that students are expected to learn at each grade is presented in less than a page. Thus, all the science content Wisconsin students are expected to learn is presented in fewer than ten pages.

To add insult to injury, the standards themselves are vacuous. A twelfth-grade physical science standard, for example, tells students:

> **Using the science themes*, illustrate* the law of conservation of energy* during chemical and nuclear reactions. (grade 12)**

No further information is provided. In fact, while the state claims that "terms with an asterisk (*) are defined and/or exemplified in the *Science Glossary of Terms*," that is only occasionally true. For instance, only two of the three terms with an asterisk in the twelfth-grade standard above can be found in the glossary.

Sad to say, this standard exemplifies the scant guidance that the state provides across grade levels and disciplines. In short, the writers have picked up boilerplate "themes" (change, constancy, equilibrium, etc.) that they only partially understand and have applied them to subject matter they clearly don't understand; the result is embarrassing. Consequently, the Badger State earns a zero out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

The introduction to Wisconsin's science standards claims that "the standards set clear and specific goals for teaching and learning," and that, while "they are not meant to supplant curriculum...they should help school districts to develop curriculum units that focus on specific academic results."

Alas, that statement couldn't be further from the truth. For instance, the content standard for earth and space science explains that, by the time they graduate, students will "demonstrate an understanding of the structure and systems of earth and other bodies in the universe and of their interactions." Yet there are only twenty-one performance objectives provided for this standard across all grades and none delineates meaningful content. Take, for example, the following expectations:

> **Develop descriptions of the land and water masses of the earth and of Wisconsin's rocks and minerals, using the common vocabulary of earth and space science. (grade 4)**
>
> **Analyze the geologic and life history of the earth, including change over time, using various forms of scientific evidence. (grade 8)**
>
> **Using the science themes*, understand* that the origin of the universe is not completely understood, but that there are current ideas in science that attempt to explain its origin. (grade 12)**

Again, such vacuity is the norm, not the exception.

In the introduction to each of the three content strands, the state includes the following note (tailored for physical, earth and space, and life and environmental sciences) that directs readers to the 1996 National Science Education Standards:

Note: For more details of the content of physical sciences, see *National Science Education Standards (1996, p. 115 - 201).**

The NSES is now fifteen years old—two years older than the Wisconsin standards. Surely, educators in Wisconsin would want to revisit these standards and supplement them with more specific content and performance expectations? Alas, no. Consequently, the state earns a zero out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

Wyoming

GRADE	SCORES		TOTAL SCORE
F	Content and Rigor	2/7	2/10
	Clarity and Specificity	0/3	

REPORT CARD

Content & Rigor	**1.5**
Scientific Inquiry & Methodology	2
Physical Science	1
Physics	1
Chemistry	1
Earth & Space Science	3
Life Science	1
Clarity & Specificity	**0.0**

Average numerical evaluations

Document(s) Reviewed

▶ *Wyoming Science Content and Performance Standards*. November 2008. Accessed from: http://edu.wyoming.gov/Libraries/Publications/Standards_2008_Science_PDF.sflb.ashx

Overview

The Wyoming science standards are—in a word—worthless, a travesty from top to bottom. How else to describe a document that does not even pay lip service to the content essential to building a curriculum? Terms appear but convey nothing tangible about their meaning or their place in a body of knowledge.

Organization of the Standards

Wyoming's science standards are divided first into three strands (called standards): science concepts and processes, science as inquiry, and the history and nature of science. Each strand is then divided into benchmarks for each of three sub-strands: life systems, earth and space science, and physical science. The benchmarks describe what students are expected to know and be able to do at each of the assessed grades—four, eight, and eleven. Finally, "performance level descriptors" articulate how well students must perform the benchmarks to be considered "advanced," "proficient," "basic," and "below basic."

No progression of grade-specific standards or benchmarks is provided.

Content and Rigor

The writers of the Wyoming science standards failed to articulate the critical science content that K-12 students should learn. In no discipline does more than a smattering of such content appear. And the few items that are included follow no logical pattern. Worse, they are abused by a lack of any context, as if the mere presence of scientific terms on a page could somehow convey knowledge. Which, of course, it cannot.

Scientific Inquiry and Methodology

The scientific inquiry and methodology standards are vague and omit nearly all of the essential content students should learn. There is virtually no coverage of the nature or history of science. Students in fourth grade, for example, are asked only to "recognize the nature and history of science" by discussing "how scientific ideas change over time," or to describe the "contributions of scientists." Sadly, no actual content or guidance is provided that might help students achieve these aims.

Worse, some critical concepts that should be introduced are missing entirely. For instance, with two exceptions, the word “theory” is absent from the standards, along with the words hypothesis and law.

Physical Science

To paraphrase Gertrude Stein, there is no there here. Most of what we consider to be essential content is missing entirely. For instance, a single benchmark, appearing in eighth grade, speaks to the structure and properties of matter:

> **The Structure and Properties of Matter: Students identify characteristic properties of matter such as density, solubility, and boiling point and understand that elements are the basic components of matter. (grade 8)**

One benchmark is simply insufficient. Moreover, although the standards do mention elements and compounds, they never use the word “atom.” And absolutely basic topics—such as molecules, units of measurement, and mixtures—are M.I.A. throughout the document.

If the writers assumed that students in the lower grades are not up to the challenge of learning about these topics, they are flatly mistaken. If they simply forgot to include the material, they are sloppy. In either case, the end result—a transmission of ignorance—is the same.

High School Physics

Wyoming reduces the entire field of thermodynamics and statistical mechanics (including the laws of thermodynamics) to fewer than thirty words. Worse still is the following eleventh-grade benchmark:

> **Force and Motion: Develop a conceptual understanding of Newton’s Laws of Motion, gravity, electricity, and magnetism. (grade 11)**

All of Newtonian mechanics, celestial mechanics, and electromagnetism is condensed to thirteen words. And sadly, too many important topics are similarly abbreviated.

High School Chemistry

Here, again, the coverage of essential content is sketchy. Atoms, electrons, and the periodic table are not mentioned until eleventh grade (about six grades too late). Bonding is mentioned, but without using the terms ionic, covalent, metallic, or hydrogen bonding, let alone citing examples of the application of these critical concepts.

Earth and Space Science

The entire earth and space science content comprises thirty-one lines, resembling more a rapid-fire list of topics than a set of standards. The material therein is broad and vague and provides no more than “study the encyclopedia” guidance.

Life Science

The Wyoming life science standards first mention evolution in the eighth-grade benchmarks, with a distinct (if subtle) creationist flavor:

> **Evolution as a Theory: Students explain evolution as a theory and apply the theory to the diversity of species, which results from natural selection and the acquisition of unique characters through biological adaptation. (grade 8)**

The term “theory” occurs only once more in the entirety of Wyoming’s standards—in a reference to the Big Bang theory (which is almost as anathematic to creationists as biological evolution). This once-commonplace trick of classifying evolution—and only evolution, among all scientific constructs—as a “theory” has been largely abandoned as too transparent. But not in Wyoming.

Oddly, this misfortune is succeeded by a sound if excessively brief account of evolution in eleventh grade:

> **Biological Evolution: Explain how species evolve over time. Understand that evolution is the consequence of various interactions, including the genetic variability of offspring due to mutation and recombination of genes, and the ensuing selection by the environment of those offspring better able to survive and leave additional offspring. Discuss natural selection and that its evolutionary consequences provide a scientific explanation for the great diversity of organisms as evidenced by the fossil record. Examine how different species are related by descent from common ancestors. Explain how organisms are classified based on similarities that reflect their evolutionary relationships, with species being the most fundamental unit of classification. (grade 11)**

And that’s it.

As for other core elements of the life sciences, the standards have nothing to say about the essential requirements of living things, or of respiration and photosynthesis, or embryogenesis, or the way that genes encode protein production, or gene expression, or the entire vast field of physiology.

Given these gaping holes in content, Wyoming receives a score of two out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

While it's true that clarity can emerge from carefully crafted terseness, that is not a characteristic of the Wyoming standards. Here, the absence of words conveys merely the absence of information.

One line in particular serves to illustrate how vague and useless the standards are. To demonstrate "basic" proficiency, fourth graders are asked to "describe what a scientist does." No further detail is provided.

The whole standards document is little more than a vocabulary list that contains terms but no definitions. And, ironically, when Wyoming does seek to offer definitions, it botches the job, with definitions that are variously empty, silly, ungrammatical, and plain ignorant. For instance, "endothermic" and "exothermic" are defined as nouns; the biosphere is described as an "area"; "biodiversity" is defined as the range of variation within a single species; the universe is vitalized in that "all things, living and nonliving, seek to attain" equilibrium; the grammatically challenged definition of Newton's laws of motion is longer than their treatment in the main text, and so on. It can be hilarious, but not helpful.

All of this is consistent with the level of the entire document. This mess is reflected in an average score of zero out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

SCIENCE

NAEP

GRADE A-

SCORES
Content and Rigor **7/7**
Clarity and Specificity **2/3**

TOTAL SCORE 9/10

Overview

The NAEP *Science Framework* for science is an extended statement of science learning expectations at grades four, eight, and twelve. The NAEP assessment is based on the science content, skills, and testing procedures outlined in the *Framework*. Sample questions show how learning expectations discussed in the *Framework* are actualized in the assessment.

Although the *Framework's* design and organization are complex and in a few places difficult to understand, in general the document works well, providing a useful epitome of K-12 science knowledge and related skills.

There are two main issues to be addressed in evaluating this *Framework*. One is length—the number of content expectations that it includes is substantial, even though limited to three grade levels. The second is purpose: How may we evaluate this *Framework*, which is conceived as a design for testing, as a set of standards that can guide curriculum making? Early in its 155 pages, the *Framework* makes this important distinction between content and curriculum:

> **Key *principles as well as facts, concepts, laws, and theories* that describe regularities in the natural world are presented…as a series of *content statements* to be assessed at grades 4, 8, and 12…[T]hese statements comprise the NAEP science content. *They define only what is to be assessed by NAEP and are not intended to serve as a science curriculum framework.* (emphasis added)**

The writers are to be congratulated for having taken the trouble thus to define "content" as used by them. Yet although the *Framework* is not intended as a comprehensive set of standards for K-12 science, it clearly does *imply* such a set. In fact, it is unlikely that state education officials, district administrators, and teachers will ignore its plentiful science content and proposed achievement levels, particularly in light of the strong influence that NAEP and its assessment results carry in American primary and secondary education. Thus, we treat the NAEP *Science Framework* here as a set of expectations for K-12 science knowledge—a.k.a. science content standards.

Organization of the Framework

NAEP sidesteps enduring debates over how to define scientific relationships among themes, principles, content, practices, scientific reasoning, inquiry, and so forth by

Document(s) Reviewed

- *Science Framework for the 2009 National Assessment of Educational Progress*. 2009. Accessed from: http://www.nagb.org/publications/frameworks/science-09.pdf
- *NAEP Science Sample Questions: Grade 4*. 2009. Accessed from: http://nces.ed.gov/nationsreportcard/pdf/demo_booklet/09SQ-O-G04-MRS.pdf
- *NAEP Science Sample Questions: Grade 8*. 2009. Accessed from: http://nces.ed.gov/nationsreportcard/pdf/demo_booklet/09SQ-G08-MRS.pdf
- *NAEP Science Sample Questions: Grade 12*. 2009. Accessed from: http://nces.ed.gov/nationsreportcard/pdf/demo_booklet/09SQ-G12-MRS.pdf

Figure 1. Crossing content and practices to generate performance expectations

		Science Content		
		Physical Science Content Statements	**Life Science Content Statements**	**Earth and Space Sciences Content Statements**
Science Practices	**Identifying Science Principles**	**Performance Expectations**	**Performance Expectations**	**Performance Expectations**
	Using Science Principles	**Performance Expectations**	**Performance Expectations**	**Performance Expectations**
	Using Scientific Inquiry	**Performance Expectations**	**Performance Expectations**	**Performance Expectations**
	Using Technological Design	**Performance Expectations**	**Performance Expectations**	**Performance Expectations**

dividing science knowledge into just two broad categories: principles and practices. The various principles comprise what is usually called science content: facts, concepts, theories, and laws. They are organized into the now-familiar content areas: physical, life, and earth and space sciences.

Next, NAEP identifies four science practices: identifying science principles, using science principles, using scientific inquiry, and using technological design.

Finally, the *Framework* designers assemble all three areas of general content (principles and their expansions) and all four general areas of practice into a matrix. Each resulting cell of this matrix is a potentially large set of performance expectations (see Figure 1). Thus for every general content area, there are four possible (and testable) practices corresponding to the *-ing* actions listed: 1) recognizing, naming, or describing the content; 2) employing the content correctly in one of its contexts; 3) showing skills needed to use that content in answering a scientific question, and 4) applying the content in a design or engineering problem.

Organization of Content Topics

Within the three main content domains (physical, life, and earth and space), how many standards do K-12 students really need to meet? In science education, at present, this is a vexed question. Some say "very few." Others say "enough to display, at least, the *range* of modern science." Still others would answer "a whole lot." NAEP settles somewhere in the middle by expanding its three content areas into eighteen foundational statements: six on physical science, five on life science, and seven on earth and space science. These are then further specified by various detailed explanations encompassing most of the basics at each assessed grade level (four, eight, and twelve), but increasing in number, sophistication, and detail from fourth grade through twelfth grade.

The physical science content area illustrates this complex structure. It is divided into six basic principles: properties of matter, changes in matter, forms of energy, energy transfer and conservation, motion at the macroscopic level, and forces affecting motion. These six principles are represented by fifteen actual content statements in fourth grade, by sixteen statements in eighth grade, and by twenty-three statements in twelfth grade. Therefore, all assessable physical science is represented in this *Framework* by fifty-four short statements of science content.

Moreover, these content statements are amplified at each grade. For example: One of the six principles of physical science is "changes in matter." In fourth grade, this principle is represented by one explicit content standard—that cooling and heating can convert matter from one recognizable state (solid, liquid, or gas) to another. In eighth grade, "changes in matter" expands to two representations, one on the molecular organization of matter and the other on chemical reactions and the conservation of mass in the course of reaction. And by twelfth grade, this principle expands to three (carefully crafted) statements, one on the energetics of state change, a second on atomic structure and electrons in atoms, and a third on chemical bonds and reactions.

In addition to the fifty-four content statements for physical science, there are thirty-two for life science and thirty-nine for earth and space science—a total of 125 explicit content statements. Since all the assessable content of K-12 science is supposed to be covered, that is not an unreasonable number.[1]

Content and Rigor

Physical Science

Content statements for fourth-grade physical science are comprehensive and emphasize properties, states, and transformations of matter. They address adequately the basics of energy and motion in grade-appropriate terms. Content statements for eighth-grade physical science—concerned with physical and chemical change—are more specific and comprehensive than are our own criteria (see Appendix A). For twelfth grade, content is strong except for light treatment of some important advanced topics of twelfth-grade chemistry (reaction mechanisms, acid-base chemistry, chemical bonds in important classes of macromolecules). Overall, the physical science content presented covers the necessary ground with neither critical omissions nor trivialities.

Earth and Space Science

The earth and space science content is well chosen. Content and sequencing concerning Earth's internal structure and plate tectonics—including the key geological evidence from seafloor spreading—are analytical and sufficiently comprehensive. For the principle "earth in space and time," the single fourth-grade expectation appropriately concerns the distinction between slow and catastrophic change. Fossils appear in eighth grade, as do mountain building and erosion. Twelfth-grade expectations expand to include, among other topics, the scale and magnitudes of geologic time. Perfect science standards would give more attention to the earth's age and to stellar evolution (as exemplified in the Hertzsprung-Russell diagram). The *Framework* gives weather and climate unusual prominence, but at the expense of astronomy and cosmology. That said, the development of scientific ideas is generally appropriate throughout the grades, and the few omissions are compensated for by careful presentation of the included content.

Life Science

Life science coverage is broad and reasonably inclusive. Basic themes—such as the mechanisms of heredity—are represented (as they should be) at all three grade levels. But "evolution and diversity," central to modern biology, does not appear until eighth grade—and some even of its simplest elements not until twelfth grade. Even then, there is no mention of the now-indispensable molecular and population genetics relevant to evolution. Somewhat disproportionate attention is paid to ecology and ecosystems (here under the thematic head of "interdependence"), and that comes at the expense—inter alia—of physiology, control systems, and developmental biology. Basic cell biology, on the other hand, is very well covered and is sequenced thoughtfully by grade.

The *Framework's* principles and detailed content statements cover virtually all the expectations spelled out in our review criteria and introduce no significant peripheral matter. A full-credit score of seven out of seven for content and rigor is justified. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

This *Framework* document concedes—as it must—that distinctions among its four basic practices are anything but sharp. They are nevertheless convenient for communicating skill expectations and for representing the underlying standards that must guide writers of test questions. The authors are evidently comfortable with the residual ambiguities, perhaps judging that they do not damage the implied standards. They make possible, presumably, the construction of fair and comprehensive tests, which is of course what the *Framework* is about. Nevertheless, while the total number of principles is appropriate, the potentially dense intersections of them and the practices (that is, the total number of principles as expanded grade by grade, multiplied by the four broad and not sharply distinguishable practices) make it difficult for a reader to comprehend a bounded set of expectations. Thus clarity is to some extent compromised by complexity; as such, the *Framework* is awarded a score of two out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)

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[1] The *Framework* reports that content selection was guided primarily by two national sources: the *Benchmarks for Science Literacy* of the American Association for the Advancement of Science (1993) and the *National Science Education Standards* of the National Research Council (1996), plus follow-up documents. The authors note, however, that those documents do not limit or prioritize content in the form of assessable units. (In fact they are often concerned with history, philosophy, and sociology of science.) The NAEP *Science Framework* concerns itself with "science" as commonly understood. And its tabulated content is justified and supported by clarifications and discussions of "crosscutting"—content relevant to more than one of the three science domains.

APPENDIX A

Methods, Criteria, and Grading Metric

Methods

This review examined the current K-12 science standards for every state plus the District of Columbia, as well as the NAEP *Science Framework*. We sought to determine how clearly, specifically, and rigorously they cover important content in four areas: physical science, life science, earth and space science, and scientific inquiry and methodology. As with other Fordham Institute reviews of state standards, this analysis focused solely on the quality of the standards themselves. We did not look at whether they are linked to a robust accountability system, whether they are being effectively implemented by a given state, or whether a state's students are achieving at high levels in the subject. Those are all crucial issues, of course, but they are also affected by many factors that go well beyond a state's expectations as expressed in its academic standards.

This is our third review of state science standards. We published the first in 1998 and the second in 2005. Our approach to this review matches that of our previous reports: We gathered the most recent version of each state's science standards from its department of education website, contacted the science standards coordinator(s) for each state to confirm the accuracy of the documents we were to review, and asked a team of trusted and top-notch content experts to apply a set of criteria to them.

For this set of reviews, Lawrence S. Lerner served as lead reviewer, while also reviewing states' K-12 physical science and high school physics standards. Ursula Goodenough reviewed states' K-12 life science standards (including those for high school biology); John Lynch, the K-12 scientific inquiry and methodology standards; Martha Schwartz, the K-12 earth and space science standards; and Richard Schwartz, the K-12 physical science and high school chemistry standards. Adam Marcus helped cobble these reviews into one cohesive document. (For further biographical information about our authors, see About the Authors, page 216.)

Between November 2010 and May 2011, Fordham staff searched the websites of state education departments and communicated with states' science experts. We sought to evaluate the most recently adopted standards. Supplemental materials, including assessment frameworks and curriculum guides, were included in this review only when they were both (a) characterized by the state department of education as a key standards document, and (b) determined by our expert reviewers to be an integral part of the state's standards.

The documents identified at the beginning of each state's profile show (and provide links to) the materials we reviewed. Fordham staff rechecked these materials in the winter of 2011 to ensure that nothing had changed. To the best of our knowledge, all standards were current as of December 2011.

In order to evaluate the quality of states' science standards, our expert reviewers devised content-specific criteria (see page 205). State standards were evaluated against the content-specific grading criteria and were judged against a common grading metric (see page 209). To increase inter-discipline comparability, the common grading metric used for this set of reviews is the same as was used in Fordham's 2010 review of mathematics and English language arts standards, *The State of State Standards—and the Common Core—in 2010*, as well as our 2011 review of U.S. history standards, *The State of State U.S. History Standards 2011*.[1]

[1] Note that the criteria used for this report differ from the criteria our experts used in both our 1998 and 2005 reviews of state science standards. Therefore, comparisons of the grades states received in each review are imperfect. Grade differences could be due to changes in a state's standards, changes in our criteria, or both.

Each state's final score is a composite based on how well the state's standards fared in two categories: (1) content and rigor, and (2) clarity and specificity. Content and rigor were scored on a zero-to-seven point scale, and clarity and specificity on a zero-to-three point scale. Reviewers scored each state's content and rigor for the reviewer's given discipline of expertise. In addition, all reviewers offered clarity and specificity scores for each state. Final content and rigor scores are the average of reviewers' individual discipline-specific scores. Final clarity and specificity scores are averages of all the reviewers' responses. The sum of these two sub-scores determined each state's final score. Final grades were converted into letter grades according to the following scale:

Grade	Points
A	10
A-	9
B+	8
B	7
C	5 or 6
D	3 or 4
F	0, 1, or 2

Content-Specific Criteria

As described above, our experts developed criteria that delineated the essential content that should be included in rigorous K-12 science standards. Following is a list of the content-specific criteria used to evaluate the state standards.

Introduction to the K-12 Science Criteria

In an effective standards document for K-12 science, instruction in the proposed content for Kindergarten through eighth grade should proceed with increasing sophistication and abstraction, as appropriate to each grade. This progression is suggested in the staged content expectations below.

Science cannot be taught effectively without carefully designed and content-matched laboratory and field activities to augment textual materials. Students' understanding of science processes and scientific discourse depends in an essential way on such activities. Laboratory work—with instruments and tools that are already available or are thoughtfully crafted for tasks that students can readily understand—is also an indispensable path to understanding relationships between science and technology and the value of good design. But standards themselves need not name specific laboratory work related to each idea; this may be done in related curriculum documents.

It is impossible to specify an absolute, minimal, "must-have" set of content items in K-12 for all modern science. Physics, chemistry, biology, geology, astronomy, and other sciences are intellectually distinct in important ways, but they are interdependent and overlapping in other ways. Quantitative thinking and problem solving are critical to all. Science content choices for elementary and middle school should include basic and unique topics from all three of the now-standard domains: physical science, life science, and earth and space science. The sequence of presentation may vary, and some areas may be omitted in some years, but this essentially arbitrary tripartite division has come into near-universal use.

For these reviews, we scored criteria against the following disciplines in the following grade spans: scientific inquiry and methodology, K-12; physical science, K-12; physics, grades 9-12; chemistry, grades 9-12; earth and space science, K-12; and life science (including high school biology), K-12.

Science Content: General Expectations for Learning through Grade Eight

Physical Science

- Know and be able to describe the common forms and states of matter, including solids, liquids, and gases, elements, compounds, and mixtures.
- Know how to use the standard units of measurement (SI).
- Understand time, rate of change, and the relationships among displacement, velocity, and acceleration.
- Understand the relationship between force and motion and be able to solve elementary problems in mechanics.
- Know how to define "gravity."
- Understand kinetic and potential energy, and their transformations.
- Know that matter is made of atoms, which are made of still smaller particles, and that atoms interact to form molecules and crystals.
- Know that heat is a mode of molecular motion. Understand temperature and explain how a thermometer works.

- Know some of the evidence that electricity and magnetism are closely related.
- Know the parts of a simple electric circuit and be able to build one.
- Recognize that light interacts with matter, as in such phenomena as emission and absorption.

Earth and Space Science

- Describe the organization of matter in the universe into stars and galaxies.
- Describe the motions of planets in the solar system and recognize our star as one of a multitude in the Milky Way.
- Recognize Earth as one planet among its solar system neighbors.
- Describe the internal layering of Earth by composition and density.
- Identify the sun as the major source of energy for processes on Earth's surface.
- Describe the main features of the theory of plate tectonics, and cite evidence supporting it.
- Understand how plate tectonics contributes to re-shaping Earth's surface and produces phenomena such as earthquakes, volcanism, and mountain building.
- Identify common minerals by their observable properties.
- Know the major rock types and how the rock cycle describes their formation.
- Understand weather in terms of such basic concepts as temperature and air pressure differences, humidity, and weather fronts.
- Distinguish between weather and climate, and describe changes in Earth's climate over time.
- Describe the hydrologic (water) cycle.
- Recognize that sedimentary rocks—and the fossils they may contain—preserve a record of conditions at the time and place in which they formed.
- Explain that the Earth environment supplies indispensable resources for humans (e.g., soil), but also creates hazards (e.g., earthquakes, volcanic eruptions, floods). Understand that human activity can protect the environment or degrade it.

Life Science

- Know requirements for the maintenance of life, both short-term and long-term, including food, appropriate environment, and efficient reproduction.
- Know how to identify, describe clearly, and name some plant and animal species, including our own.
- Identify the broadest physical and chemical characteristics of Earth's biota.
- Show familiarity with structure and function in prokaryotic and eukaryotic cells and in the tissues of multicellular organisms.
- Know the elements of biological energetics, including cellular respiration and photosynthesis.
- Trace major events in the history of life on earth, and understand that the diversity of life (including human life) results from biological evolution.
- Identify and describe the basic stages of gamete formation and embryogenesis in animals.
- Understand Mendel's laws, phenotype, and genotype.
- Recognize that genes are made of nucleic acids and encode the structure of proteins.
- Recognize the significance of differential gene expression in the processes of development.
- Know the operations of some biochemical and physiological systems (e.g., digestive, sensory, circulatory) in microbes, plants, and animals—including humans.
- Be able to offer examples of cooperation and competition among plants and animals in groups, in populations, and in ecosystems.

Science Content: General Expectations for Learning for Grades Nine through Twelve[2]

Between ninth grade and high school graduation, many (but not all) students take only one full, two-semester science course. Others may take an "integrated" science course or courses. Elective opportunities, including AP courses, are widespread. The expectations shown here must, therefore, be read selectively and with care. The physics content shown, for example, is primarily, but not necessarily, limited to students who have taken high school physics.

High School Physics

- Use Newton's laws quantitatively to describe falling bodies, linear and curvilinear motion, simple harmonic motion, and fixed-axis rotation.

[2] Note that in the K-8 standards, physics and chemistry content is combined under the heading "physical science." At the high school level, standards for physics and chemistry should be broken out and presented separately. Our criteria reflect this difference.

- Describe planetary motion using Kepler's laws and explain how those laws derive from Newton's laws of motion.
- Use momentum and energy conservation laws to describe one-dimensional elastic collisions.
- Use the work-energy theorem to explain the constancy of total mechanical energy in a frictionless system (e.g., a bouncing Super Ball).
- Understand and describe the absolute temperature scale, the Celsius and Fahrenheit scales, and be able to convert from one to another.
- Explain the first law of thermodynamics in terms of the concepts of heat flow, work, and internal energy.
- Use the operation of an idealized heat engine/heat pump to explain the concepts of thermodynamic efficiency and coefficient of performance. Evaluate the efficiency of heat engines and the performance of refrigerators.
- Understand and be able to apply basic electromagnetic quantities, including charge, polarity, field, potential, current, resistance, capacitance, inductance, and impedance.
- Understand simple electric and electronic circuits quantitatively, in terms of currents and voltage drops.
- Understand how electromagnetic radiation results from the interaction of changing electric and magnetic fields. Analyze refraction and reflection at an optical interface.
- Recognize the basics and some applications of spectrometry.
- Describe the photoelectric effect and the production of X-rays.
- Describe elementary particles and distinguish matter and radiation.

High School Chemistry

- Outline the Bohr and quantum mechanical models of the atom, and relate them to spectral lines and electron transitions. Understand and give examples of the role of ionic, metallic, covalent, and hydrogen bonding in chemical and biochemical processes.
- Be able to use Lewis dot structures to predict the shapes and polarities of simple molecules.
- Use kinetic theory to describe the behavior of gases (i.e., the ideal gas law) and phase changes.
- Understand and apply the basic principles of acid-base and oxidation-reduction chemistry.
- Understand the common factors that affect the rate of a chemical reaction (e.g., catalysis).
- Describe dynamic equilibrium processes as ones in which forward and reverse reactions occur at the same rates and how a system at equilibrium reacts when stressed.
- Write and balance equations for chemical reactions; solve stoichiometric problems using moles and mole relationships.
- Understand the role of carbon in organic chemistry; write structural formulas for simple aliphatic and aromatic compounds, and name them correctly.
- Calculate the concentration of solutions (as molarity and percent) and discuss factors that affect solubility.
- Use the periodic table to discern and predict properties of atoms and ions, and the likelihood of chemical reactions taking place among them.

Earth and Space Science

- Cite and explain evidence that the universe has been evolving over some fourteen billion years.
- Describe important events in Earth and solar system evolution over the past four billion years.
- Explain the main events in the evolution of stars and how a star's initial mass determines its eventual fate.
- Know the main physical characteristics of solar system planets and their major satellites.
- Understand and use correctly the basic units of astronomical distance.
- Explain methods of relative and absolute dating of rocks.
- Explain why earthquakes occur, how their sizes are reported as intensity and magnitude, and how scientists use data to locate an earthquake's epicenter.
- Summarize the main lines of evidence for the existence and motion of tectonic plates.
- Describe the movement of continents in terms of mantle convection, lateral motion, seafloor spreading, and subduction at the boundaries between plates.
- Show where Hawaiian-style and Vesuvian-style volcanoes are located in relation to plate boundaries and mantle hot spots, and compare their eruption styles and the structures they build.
- Describe climate and weather patterns in terms of latitude, elevation, oceans (with reference to special properties of water, such as specific heat), land, heat, evaporation, condensation, and rotation of the planet.

- Describe the greenhouse effect and how a planet's atmosphere can affect its climate.
- Describe the solar cycle; be aware of possible effects of solar activity variation on Earth.
- Describe how nutrients, such as carbon, cycle through the atmosphere, hydrosphere, and solid earth.

Life Science

- Describe the differences between prokaryotes and eukaryotes and probable evolutionary relationships between them.
- Describe ultrastructure and functions of the principal subcellular organelles.
- Understand the distinctions between asexual and sexual reproduction.
- Identify landmark stages of mitosis and meiosis, the purpose of meiosis, and key stages of early development and morphogenesis in animals.
- Be able to state and apply Mendel's laws and to recognize their operation in genetic crosses.
- Know the basic structures of chromosomes and genes down to the molecular level.
- Know the principal steps in photosynthesis, its contribution to the evolution of Earth's atmosphere, and its effect on the forms and chemistry of green plants.
- Understand the genetic code and the steps by which it is expressed in protein synthesis.
- Provide evidence to support the central role of differential gene expression in cellular differentiation and development (e.g., the role of Hox genes).
- Compare and contrast the structure and function of basic physiological systems in animals and higher plants (e.g., digestive, circulatory, sensory, reproductive).
- Define natural selection and speciation in terms of population and evolutionary genetics.
- Understand how evolutionary relationships are inferred with the help of gene/genome sequencing.
- Define genetic drift and explain its effect on the probability of survival of mutations.
- Recognize and give examples of the main classes of ecosystem and their structures.
- Give examples of ecological change that can drive evolutionary change.

Sample Content Expectations at Specific Stages (Points of Assessment)

Fourth Grade

- Distinguish among solids, liquids, and gases.
- Recognize sizes and scales; know measuring tools and techniques (e.g., rulers, balances, thermometers); make and interpret elementary bar and line graphs to display data.
- Be able to discuss motion and its causes: pushes and pulls (i.e., forces).
- Know how to observe and record operations of levers, pulleys, objects on inclined planes, spring-mass systems, and simple pendulums.
- Recognize that energy has several forms and that they can be inter-converted.
- Observe and describe some material transformations (e.g., phase changes, hydration, dehydration, solution, chemical reaction).
- Recognize such basic life processes as breathing, feeding, and reproducing.
- Know the basic structure of higher plants; observe plant growth and its requirements.
- Recognize animal structures and behaviors and the groupings of animals and plants in communities.
- Observe and be able to describe similarities and differences between parents and offspring.
- Observe Earth, the sun, and the moon and discuss their motions and directly visible properties.
- Recognize rocks, soil, and fossils in rocks; land and water; mountains and plains; oceans and continents.
- Recognize some conditions and processes that cause weathering and erosion, stream formation, and sedimentation.

Eighth Grade

- Make measurements and perform calculations, paying attention to precision and accuracy.
- Make and interpret graphical displays of data.
- Understand and make simple calculations involving displacement, time, and average velocity.
- Define volume, weight, mass, density, and chemical and physical change.
- Demonstrate addition of forces in one dimension and explain the relationship between net force and acceleration.

- Describe mechanical work as the effect of a force acting over a distance, and explain that the work done in lifting a mass or compressing a spring is stored as potential energy.
- Demonstrate basic familiarity with heat, light, sound, and electricity.
- Distinguish between, and give examples of, elements and chemical compounds.
- Describe directly observable properties of acids and bases and use of the pH scale.
- Describe accurately key differences between prokaryotic and eukaryotic cells.
- Recognize photosynthesis as a primary energy-capture process of life, and the sun as the indispensable source of that energy.
- Recognize and be able to express in simple taxonomic terms the vast range of plant and animal diversity.
- Identify structure/function relationships in physiological systems (e.g., reproductive, digestive, nervous, circulatory).
- Know the elements of Mendelian inheritance.
- Be aware of the history of Earth's biosphere and some of the basic evidence for its evolution.
- Understand that Earth is geologically active, with building and breakdown processes in continual operation.
- Know the rock cycle.
- Describe the solar system and know some relative orbit radii, periods, and planet and satellite sizes.
- Recognize the existence of myriad galaxies, their sizes, and intergalactic distances.

Common Grading Metric

As explained above, once a state's standards are evaluated against the science content criteria, the standards are judged against a grading metric (shown below). States can earn up to seven points for content and rigor, and up to three points for clarity and specificity.

Content and Rigor

7 points – Standards meet all of the following criteria:

- Standards are reasonably comprehensive in terms of content. Coverage for each of the three core scientific disciplines is adequate, and good decisions have been made about what topics to include under each heading.
- Not only is appropriate content covered by the standards, but it is also articulated in a readily understood way.
- Sound decisions have been made about what content can be left out. Excellent standards can neither cover everything in science nor include superfluous or distracting material.
- The standards distinguish between more important and less important content and skills, either directly (by stating which are more and less important) or via the number of standards and amount of discussion devoted to particular topics. The standards neither overemphasize topics of small importance nor underemphasize topics of great importance.
- The level of rigor is appropriate for targeted grade level(s). Students are expected to learn the content and skills in a rational order and at appropriately increasing levels of difficulty. The standards, taken as a whole, define science literacy for all students; at the same time, standards that run through twelfth grade are sufficiently challenging to ensure that students who do achieve proficiency by the final year will be ready for college or career.
- The standards do not overemphasize "life experiences" or "real world" problems. They do not embrace fads or display political or cultural biases. They do not imply that all interpretations of natural phenomena are equally valid. While these standards may not be uniformly perfect, any defects are marginal.

6 points – Standards fall short in one of the following ways:

- Some important content (as identified in our content criteria) is missing.
- Content is covered satisfactorily but the presentation is not of uniformly high quality.
- Some proposed content in the standards is unnecessary and distracting.
- Standards do not always differentiate between more and less important content (i.e., importance is neither articulated explicitly nor conveyed via the number of standards dedicated to a particular topic). In other words, these standards overemphasize a few topics of little importance or underemphasize a few topics of great importance.
- Some of the expectations at particular grade levels are set either unrealistically high or too low.
- There are small problems or errors in the presentation of important subjects, such as those listed among our content criteria.

5 points – Standards fall short in <u>at least two</u> of the following ways:

- Some important content (as identified in our content criteria) is missing.
- Content is covered satisfactorily but the presentation is not of uniformly high quality.
- Some proposed content in the standards is unnecessary and distracting.
- Standards do not always differentiate between more and less important content (i.e., importance is neither articulated explicitly nor conveyed via the number of standards dedicated to a particular topic). In other words, these standards overemphasize a few topics of little importance or underemphasize a few topics of great importance.
- Some of the expectations at particular grade levels are set either unrealistically high or too low.
- There are a few problems or errors in the presentation of important subjects, such as those listed among our content criteria.

4 points – Standards fall short in <u>one or both</u> of the following ways:

- Although there are no grossly misleading or mistaken standards, about half of the important content (as listed among our content criteria) is missing.
- There are errors or failures to set learning expectations high enough and appropriate to grade level.

3 points – Standards fall short in <u>one or both</u> of the following ways:

- Although there are no grossly misleading or mistaken standards, considerably more than half of the important content (as listed among our content criteria) is missing.
- There are frequent errors or failures to set learning expectations high enough and appropriate to grade level.

2 points – Standards fall short in <u>one</u> of the following ways:

- Most, but not necessarily all, of the important science content (as represented in our content criteria) is missing.
- Some of the content offered is superfluous or distracting; even if not in error, it often fails to reach levels of sophistication that are grade-appropriate.

1 point – Standards fall short in <u>both</u> of the following ways:

- Most, but not necessarily all, of the important science content (as represented in our content criteria) is missing.
- The content offered is frequently superfluous, distracting, or poorly chosen; even if not in error, it generally fails to reach levels of sophistication that are grade-appropriate.

0 points: Standards fall short in the following way:

- No effort has been made to represent the state and content of modern science; that is, the character and content of modern science are not recognizable in these standards.

Clarity and Specificity

3 points – Standards are clear, coherent, and well organized.

Both scope and sequencing of the material are apparent and reasonable. The standards provide practical guidance to users (students, parents, teachers, curriculum directors, test developers, textbook writers, etc.) on the science content knowledge and skills required. The level of detail is appropriate for expectations covering all K-12 science.

The document(s) is (are) written in prose that the general public can understand and that is free of jargon. (Necessary technical terms and mathematical notation may appear; they are not considered jargon.) The standards describe measurable achievements—performance levels comparable across students and schools. The standards as a whole make clear the intellectual growth expected through the grades.

2 points – The standards are somewhat lacking in clarity, coherence, or organization.

Scope and sequencing of the material are not completely apparent or are not always useful for curriculum planning. The standards do not quite provide a complete guide for users as to the content knowledge and skills required. (That is, as a guide for users, these standards have shortcomings not addressed directly in the content and rigor review.) The standards provide insufficient detail. The prose is generally comprehensible but there is some jargon or vague language. Some of the standards do not imply measurable expectations.

1 point – The standards fail frequently to be clear, coherent, or well organized.

The standards offer only limited guidance to users (students, parents, teachers, curriculum directors, textbook writers, etc.) on the content knowledge and skills required, and there are shortcomings (regarding guidance for users) that are not addressed directly in the content and rigor review. The standards are seriously lacking in detail, and the language is sometimes too vague to make clear what is really being asked of students and teachers.

0 points – The standards are incoherent and/or disorganized.

The standards will not be helpful to users. They are sorely lacking in detail. Scope and sequence are a mystery.

APPENDIX B

Detailed Grades, 2012

Table B-1. Detailed Science Grades; Jurisdiction in Rank Order

JURISDICTION	GRADE	TOTAL SCORE	CONTENT AND RIGOR SCORE (Out of 7)	CLARITY AND SPECIFICITY SCORE (Out of 3)
California	A	10	7	3
District of Columbia	A	10	7	3
Indiana	A-	9	6	3
Massachusetts	A-	9	6	3
NAEP Framework	*A-*	*9*	*7*	*2*
South Carolina	A-	9	6	3
Virginia	A-	9	6	3
New York	B+	8	6	2
Arkansas	B	7	5	2
Kansas	B	7	5	2
Louisiana	B	7	5	2
Maryland	B	7	5	2
Ohio	B	7	5	2
Utah	B	7	5	2
Connecticut	C	6	4	2
Georgia	C	6	4	2
Michigan	C	6	4	2
Missouri	C	6	4	2
New Mexico	C	6	4	2
Texas	C	6	5	1
Washington	C	6	3	3
Delaware	C	5	3	2
Florida	C	5	3	2
Minnesota	C	5	4	1

Table B-1. Detailed Science Grades; Jurisdiction in Rank Order (cont'd)

JURISDICTION	GRADE	TOTAL SCORE	CONTENT AND RIGOR SCORE (Out of 7)	CLARITY AND SPECIFICITY SCORE (Out of 3)
Mississippi	C	5	4	1
Vermont	C	5	3	2
Alabama	D	4	3	1
Arizona	D	4	3	1
Hawaii	D	4	3	1
Illinois	D	4	3	1
Maine	D	4	3	1
New Hampshire	D	4	3	1
North Carolina	D	4	3	1
Rhode Island	D	4	2	2
Tennessee	D	4	3	1
West Virginia	D	4	3	1
Colorado	D	3	2	1
Iowa	D	3	2	1
Kentucky	D	3	2	1
Nevada	D	3	2	1
New Jersey	D	3	2	1
Pennsylvania	D	3	2	1
Alaska	F	2	1	1
Idaho	F	2	2	0
Nebraska	F	2	1	1
Oklahoma	F	2	1	1
Oregon	F	2	1	1
South Dakota	F	2	1	1
Wyoming	F	2	2	0
Montana	F	1	1	0
North Dakota	F	1	1	0
Wisconsin	F	0	0	0

Table B-2. Detailed Science Grades; Jurisdiction in Alphabetical Order

JURISDICTION	GRADE	TOTAL SCORE	CONTENT AND RIGOR SCORE (Out of 7)	CLARITY AND SPECIFICITY SCORE (Out of 3)
Alabama	D	4	3	1
Alaska	F	2	1	1
Arizona	D	4	3	1
Arkansas	B	7	5	2
California	A	10	7	3
Colorado	D	3	2	1
Connecticut	C	6	4	2
Delaware	C	5	3	2
District of Columbia	A	10	7	3
Florida	C	5	3	2
Georgia	C	6	4	2
Hawaii	D	4	3	1
Idaho	F	2	2	0
Illinois	D	4	3	1
Indiana	A-	9	6	3
Iowa	D	3	2	1
Kansas	B	7	5	2
Kentucky	D	3	2	1
Louisiana	B	7	5	2
Maine	D	4	3	1
Maryland	B	7	5	2
Massachusetts	A-	9	6	3
Michigan	C	6	4	2
Minnesota	C	5	4	1
Mississippi	C	5	4	1
Missouri	C	6	4	2
Montana	F	1	1	0
NAEP Framework	*A-*	*9*	*7*	*2*
Nebraska	F	2	1	1
Nevada	D	3	2	1
New Hampshire	D	4	3	1
New Jersey	D	3	2	1
New Mexico	C	6	4	2
New York	B+	8	6	2
North Carolina	D	4	3	1
North Dakota	F	1	1	0

Table B-2. Detailed Science Grades; Jurisdiction in Alphabetical Order (cont'd)

JURISDICTION	GRADE	TOTAL SCORE	CONTENT AND RIGOR SCORE (Out of 7)	CLARITY AND SPECIFICITY SCORE (Out of 3)
Ohio	B	7	5	2
Oklahoma	F	2	1	1
Oregon	F	2	1	1
Pennsylvania	D	3	2	1
Rhode Island	D	4	2	2
South Carolina	A-	9	6	3
South Dakota	F	2	1	1
Tennessee	D	4	3	1
Texas	C	6	5	1
Utah	B	7	5	2
Vermont	C	5	3	2
Virginia	A-	9	6	3
Washington	C	6	3	3
West Virginia	D	4	3	1
Wisconsin	F	0	0	0
Wyoming	F	2	2	0

About the Authors

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Ursula Goodenough is a professor of biology at Washington University. She received her Ph.D. in biology from Harvard University, and previously served there as an NIH postdoctoral fellow and both an assistant and an associate professor. At Washington University, she runs the Goodenough Lab, which utilizes the unicellular green soil alga, *Chlamydomonas reinhardtii*, to study both fundamental and potentially industry-applicable biological processes. Her long-term focus has centered on elucidating molecular-genetic features of its sexual cycle, leading to the cloning and characterization of its mating-type locus and of genes involved in sex determination, mating interactions, the haploid-diploid transition in gene expression that follows gametic fusion, and the uniparental inheritance of chloroplast genomes. She teaches cell biology and molecular evolution and has written three editions of a widely used college textbook on genetics. She has acted as president of the American Society for Cell Biology, among other positions of leadership in the organization, and she serves on national science committees, review panels, and editorial boards. She is the author of *The Sacred Depth of Nature* (Oxford University Press, 1998).

Paul R. Gross

Paul R. Gross was educated in Philadelphia public schools and at the University of Pennsylvania. He held a senior postdoctoral fellowship of the U.S. National Science Foundation at the University of Edinburgh, and was awarded an honorary D.Sc. from the Medical College of Ohio. Now professor emeritus of life sciences at the University of Virginia, Paul Gross previously served as the university's vice president and provost, founding director of the Markey Center for Cell Signaling, and director of the university's Shannon Center for Advanced Studies. He is a fellow of the American Academy of Arts and Sciences, and has taught and directed research at New York University, Brown University, the Massachusetts Institute of Technology, and the University of Rochester (where he was chairman of biology and dean of graduate studies). He was director and president of the Marine Biological Laboratory, Woods Hole, Massachusetts, from 1978–88, and has served as a trustee of Associated Universities, Inc., and of the American Academy of Liberal Education. The research of Dr. Gross and his students and fellows has centered on the molecular biology of development and cellular differentiation. His published works include numerous articles, essays, and books on topics ranging from fertilization and early animal development to contemporary issues in science, education, and culture. His most recent book (with philosopher Barbara Forrest) is *Creationism's Trojan Horse* (Oxford University Press, 1998).

Lawrence S. Lerner

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