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# The State of Engineering Integration in K-12 Science Standards: Five Years After NGSS (Fundamental)

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# The State of Engineering Integration in K-12 Science Standards Five Years After NGSS

Abstract

Recent initiatives in engineering education have resulted in the integration of engineering concepts directly into K-12 education standards. The most notable example of this is the Next Generation Science Standards (NGSS), released in 2013. The NGSS not only includes standards focused directly on engineering, but also lists engineering design as one of four primary domains of science.

Since educational standards are defined on a state-by-state basis, the direct impact of the NGSS is limited to the states which choose to adopt them. Beyond this, however, the NGSS have an indirect impact as a concrete and well-known example of engineering integration, and as an inspiration for additional states to reconsider their own standards in the light of NGSS. Work by Tamara Moore and colleagues provides a detailed reference point for the state of engineering in science standards at the time of the NGSS publication, however many science standards have been changed across the country in the five years since the NGSS were first published. Since their release, the NGSS have been adopted by 20 states, and eight others have implemented standards based on the NGSS themselves or the framework behind the NGSS.

This paper provides a summary of the current state of engineering integration in science standards across the nation. It first includes a brief overview of the development NGSS and then describes how the NGSS has influenced state science standards across the country. Timelines of standard adoption for states that adopted the NGSS and states that adopted modified standards based on them are presented. Also, states that have not changed their standards, and states that have published new or updated science standards not based on the NGSS since 2011 will be mentioned for completeness. This paper concludes with recommendations for future research.

## K-12 Engineering

Engineering has traditionally been taught only at the post-secondary level, however recent efforts have focused on developing engineering knowledge and interest in elementary and secondary school students. This is largely in response to a perceived national need to increase the population of students going into Science, Technology, Engineering and Math (STEM) fields and stay internationally competitive in technical fields (PCAST, 2012).

In recent years, the push towards K-12 engineering education has been directed toward the development of engineering content standards in order to precipitate widespread integration of engineering. In his discussion on the role of educational standards and the need for K-12 engineering standards, Rodger Bybee, an NGSS writing leader, stated that “the power of national standards lies in their potential capacity to change the fundamental components of the education system at a scale that makes a difference” (Bybee, 2011). The work on engineering content standards is also part of a larger educational shift towards standards-based education. As an example of this shift, the Common Core standards for English and Mathematics were adopted by forty of the fifty states (although later repealed in a few states).

In 2010, the National Academy of Engineering published a book discussing whether K-12 standards should be developed for engineering, and if so how they should be incorporated into the curriculum. After reviewing several approaches, the authors recommended that engineering standard be integrated into existing science standards to emphasize the symbiotic interaction of engineering and science practices. The conclusion to integrate engineering standards into other STEM standards also reflects a larger-scale goal of integrating engineering learning goals together into a networked model, as described by Sheppard, Macatangay, Colby, & Sullivan (2008). By integrating engineering into science standards, students learn about scientific knowledge, engineering applications, and technical communication and inquiry all together rather than in individual silos that decontextualize each topic.

After nearing consensus on integrating engineering into science standards, the community next had to answer the question of what engineering standards should look like. In 2013, the National Research Council published a new framework for science education that outlined practices, core disciplinary ideas, and crosscutting concepts that should run throughout an ideal set of science standards. Engineering was woven through this framework as a practice, a domain of disciplinary ideas, and an element in two of the crosscutting concepts. Researchers at Purdue also did work to establish what would constitute a quality engineering education at the K-12 level and created a list of nine indicators that should be present (Moore, et al., 2014).

The Next Generation Science Standards

From 2010 to 2013, a group of 40 educators and leaders, representing 26 states, coordinated by Achieve, worked to implement the NRC framework as a classroom-ready set of standards. Their final work was published in April of 2013 as the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). The NGSS implements the practices, disciplines, and crosscutting concepts directly from the framework, and includes engineering throughout the standards.

Based on its foundation in the NAE and NRC publications, the structure of the NGSS strongly supports the networked model of engineering education described by Sheppard (2008). By describing Engineering as a practice and as a domain of disciplinary ideas, and weaving nine cross cutting concepts through both engineering design and scientific principles, the NGSS is designed to tie together the various learning goals of science education in a cohesive and integrated way. For a more detailed analysis of how the NGSS incorporates engineering, particularly with respect to the key indicators of Moore et al. (2014), see Moore, Tank, Glancy, and Kersten (2015).

State of Engineering Integration Prior to NGSS

In order to understand how NGSS has shifted the landscape of K-12 engineering standards, we must first look at the state of engineering standards integration prior to the NGSS. In a 2012 publication, Carr, Bennett, and Strobel asked the question “To what extent is engineering present in current STEM standards in the 50 states in the USA?” To answer this question, the authors analyzed science, math, technology, vocational, career and engineering content standards from 2011. They found that 11 states had explicit engineering standards, and another 19 referenced explicit engineering content from either Project Lead the Way, or the International Technology and Engineering Educators Association. Of the remaining states, 11 alluded to engineering, often in the context of technology, and 9 made no reference to engineering in their standards.

In a 2015 publication, Moore et al. analyzed the science standards of all 50 states (as of Dec 2011) just before the publication of the NGSS. Their guiding research question strongly paralleled that of Carr et al. but within the limited scope of science standards, and with an additional focus on quality: “What is the extent and quality of the engineering that is present in state science standards and the Next Generation Science Standards?” Results indicated 12 states with explicit references to engineering, and 24 with implicit references to engineering that included indicators such as the Process of Design, Testing, and Application of Science Knowledge. Including all of these categories, Moore et al. noted that, on average, states with explicit engineering integration had nearly three times more standards with engineering concepts than states that only implicitly mentioned engineering.

For a state-by-state comparison of Carr and Moore’s results, see Table 3. Since Carr and Moore conducted their analysis on standards from the same year, their results largely align. A careful look at Table 3 will show that states Carr identified as integrating engineering into their science standards (indicated with an asterisk) have been similarly categorized by Moore. In addition, the states Carr identified as including engineering in other standards often had implicit references to engineering in their science standards according to Moore.

Current Landscape

Since Moore’s analysis in 2011, the landscape of engineering integration in K-12 science standards has shifted greatly. To understand the current landscape, science standards for each of the fifty states were retrieved from state websites and categorized. Reference information for the websites used can be found in the appendix. Results presented here are a current reflection of information available online as of April 2018.

Since 2011, 39 states have updated their science standards. The other 11 states (AK, AZ, CO, FL, ME, MN, NC, ND, NM, PA, and VA) still have in place the standards analyzed and reported on by Moore. However, several of these (Arizona, Colorado, Minnesota, and North Dakota) have announced plans to revise their science standards in the next two years. As of April 2018, the draft science standards proposed in Arizona reflect the NRC framework, although they do not directly parallel the NGSS. Pennsylvania did adopt new standards in 2012 for grades pre-K – 3, however these are comparable in engineering integration to the grades 4-12 standards already in place during Moore’s analysis, and so are not considered a meaningful change for the purposes of this paper.

There are 20 states (AR, CA, CT, DE, HI, IA, IL, KY, KS, MD, NH, NJ, NV, NY, OR, RI, VT, WA, WI, WY) that have effectively adopted the NGSS since their release in 2013. Many of these states adopted them under a different, state-specific name, and some added a few state-specific standards, but all retained the structure, content, connections, and specific wording found in the original NGSS. For example, Wisconsin added an additional standard on the nature of science and engineering, some states do not list “Interdependence of science, engineering, and technology" and "Influence of engineering, technology, and science on society and the natural world" as crosscutting concepts, although individual standards directly quote the NGSS versions which include these concepts, and New Jersey includes "Engineering, Technology, And Applications Of Science" (ETS) standards with the Earth and Space Sciences standards rather than under their own heading. However, these changes make no significant difference in the overall body of standards. A few states also modified standards related to climate change and the age of the earth, which though controversial in some settings, are not relevant to our present analysis of the integration of engineering. In addition to the states listed, after many heated debates, New Mexico has indicated its intention to adopt the NGSS in July 2018.

Table 1 shows the states that have adopted the NGSS, in order of adoption. Ten states adopted the NGSS within a year of its release, and another 10 states have adopted them in the years since. The first 14 adoptees were all NGSS lead states that participated in the development of the standards, making Connecticut the first state to adopt the standards that had not been involved in their development.

Adoption of NGSS

| | |
|---|---|
| Release | 9-Apr-13 |
| Rhode Island (N) | 23-May-13 |
| Kentucky (N) | 5-Jun-13 |
| Kansas (N) | 11-Jun-13 |
| Maryland (N) | 25-Jun-13 |
| Vermont (N) | 25-Jun-13 |
| California (N) | 4-Sep-13 |
| Delaware (N) | 19-Sep-13 |
| Washington (N) | 1-Oct-13 |
| Illinois (N) | 23-Jan-14 |
| Nevada (N) | 26-Feb-14 |
| Oregon (N) | 6-Mar-14 |
| New Jersey (N) | 9-Jul-14 |
| Arkansas (N) | 10-Jun-15 |
| Iowa (N) | 6-Aug-15 |
| Connecticut | 4-Nov-15 |
| Hawaii | 19-Feb-16 |
| Wyoming | 23-Sep-16 |
| New Hampshire | 3-Nov-16 |
| New York (N) | 12-Dec-16 |
| Wisconsin | 17-Nov-17 |
| New Mexico | Pending (1-Jul-18) |

Table 1 - A timeline of the adoption of the NGSS.
(N) indicates NGSS lead states.

Adoption of Standards Based on NGSS

| | |
|---|---|
| South Carolina | Jan-2014 |
| Oklahoma | Mar-2014 |
| West Virginia (N) | Apr-2015 |
| South Dakota (N) | May-2015 |
| Alabama | Sep-2015 |
| Georgia (N) | Mar-2016 |
| Utah (grades 6-8) | Dec-2015 |
| Missouri | Apr-2016 |
| Michigan (N) | May-2016 |
| Montana (N) | Sep-2016 |
| Tennessee (N) | Oct-2016 |
| Louisiana | Mar-2017 |
| Nebraska | Sep-2017 |
| Massachusetts (N) | Nov-2017 |
| Mississippi | 2018 |

Table 2 - A timeline of the adoption of standards based on the NGSS.
(N) indicates NGSS lead states.

Comparison of Engineering Integration from 2011 to 2018

| | 2011 | 2011 | 2018 |
|---|---|---|---|
| Alabama | EX | IM | IM |
| Alaska | IM | IM | IM |
| Arizona (N) | IM | IM | IM |
| Arkansas (N) | | | EX (NGSS) |
| California (N) | EX | | EX (NGSS) |
| Colorado | EX | | |
| Connecticut | EX | IM | EX (NGSS) |
| Delaware (N) | EX | IM | EX (NGSS) |
| Florida | EX | IM | IM |
| Georgia (N) | EX | | IM |
| Hawaii | EX | IM | EX (NGSS) |
| Idaho | EX | IM | --- |
| Illinois (N) | * EX | EX | EX (NGSS) |
| Indiana | * EX | EX | --- |
| Iowa (N) | EX | IM | EX (NGSS) |
| Kansas (N) | * EX | EX | EX (NGSS) |
| Kentucky (N) | | IM | EX (NGSS) |
| Louisiana | | | IM |
| Maine (N) | * IM | EX | EX |
| Maryland (N) | EX | IM | EX (NGSS) |
| Massachusetts (N) | * EX | EX | EX |
| Michigan (N) | IM | IM | EX |
| Minnesota (N) | * EX | EX | EX |
| Mississippi | EX | IM | EX |
| Missouri | EX | IM | EX |
| Montana (N) | | | IM |
| Nebraska | * IM | IM | EX |
| Nevada | | | EX (NGSS) |
| New Hampshire | EX | IM | EX (NGSS) |
| New Jersey (N) | EX | | EX (NGSS) |
| New Mexico | | | |
| New York (N) | * EX | EX | EX (NGSS) |
| North Carolina (N) | EX | | |
| North Dakota | EX | IM | IM |
| Ohio (N) | EX | | --- |
| Oklahoma | | EX | |
| Oregon (N) | * EX | EX | EX (NGSS) |
| Pennsylvania | EX | EX | EX |
| Rhode Island (N) | EX | | EX (NGSS) |
| South Carolina | IM | IM | EX |
| South Dakota (N) | IM | IM | IM |
| Tennessee (N) | * EX | EX | EX |
| Texas | EX | IM | --- |
| Utah | EX | IM | EX |
| Vermont (N) | * IM | IM | EX (NGSS) |
| Virginia | | | |
| Washington (N) | * IM | EX | EX (NGSS) |
| West Virginia (N) | IM | IM | EX |
| Wisconsin | IM | IM | EX (NGSS) |
| Wyoming | | | EX (NGSS) |

Legends

| | |
|---|---|
| EX | Explicit Engineering Standards |
| IM | Implicit Reference to Engineering |
| | No Engineering |
| --- | Not Reported |

| | |
|---|---|
| * | Engineering found in *Science* standards |
| (N) | NGSS Lead state |

Table 3 - The extent to which engineering is integrated into state K-12 standards. The first column represents the results of Carr, et al., looking at all educational standards. The second column represents the results of Moore, et al., looking at only science standards, and the final column represents the current state of science standards as reported in this paper.

In addition to the states that have adopted the NGSS, another 15 states have developed new standards that have been heavily influenced by the NGSS, and/or the NRC framework. Seven states (LA, MI, MT, NE, OK, SD, WV) included the NGSS standards, but added several state-specific aspects, and organized the standards and their related concepts differently than the original NGSS. Of particular note however, is that Louisiana, Montana, and South Dakota did not include the ETS standards along with the rest of the standards, although they left it as a disciplinary core idea, and Oklahoma left it out altogether. An additional eight states (AL, GA, MA, MO, MS, SC, TN, UT) wrote their own standards based on the structure of the NRC framework, including the disciplinary core ideas and crosscutting concepts, and even borrowed concepts and wording from the NGSS, but included significant revisions or rewrites. Because of their foundation in the NRC framework most of these states had many explicit references to engineering throughout their standards, however Alabama and Georgia left out ETS standards, and Utah only updated standards for grades 6-8. Table 2 shows the adoption timeline for these eight states.

Four states are left out of the analysis of this paper. While these states (ID, IN, OH, TX) have developed new standards since 2011, they made no explicit reference to the NGSS or the NRC framework in their development process. Therefore, there is no clear path to claim that the NGSS and supporting work has had any influence in these states. These states are marked with a "---" in Table 3 to denote that the current integration of engineering in their science standards is unknown. It is likely that they have a similar profile of engineering to their previous standards documented by Moore, et al., but further analysis would be necessary to determine this.

## Conclusions and Recommendations

Though only 10 states adopted the NGSS within the first year, the standards have had a much broader impact than that number would indicate. Over 70% of states are now using a set of science standards influenced by the NRC framework and the NGSS, and over 80% include some reference to engineering in their standards. This finding has several implications for future research and practice. First, the process of developing standards can have great influence on U.S. education at a systematic level. Though the process takes quite a few years to unfold, change does (slowly) happen and a single project can have a nationwide impact. This is an encouragement and possible direction for educators and researchers who see the need to make systemic change.

Secondly, there are many research opportunities to study the influence of the NGSS on a more granular level by tracking changes as states progress through multi-year implementation plans. Most states that have adopted the NGSS, or similar standards, have also developed plans to integrate their new standards into current curriculum, instruction, and assessment over a period of three to five years. Even Rhode Island, the first state to adopt, continued to use assessments aligned with their former standards through 2017. Thus, as the effect of the NGSS continues to trickle down to teachers, classes, and individual students, much research needs to be done to assess impacts on teaching practices, student learning outcomes, and eventually, student trajectories beyond high school. The next few years will be a key time for these research directions as states reach a point of full implementation.

Finally, the prevalence of engineering in state standards now creates a content knowledge gap for science teachers trained to teach only classic science topics. Over 60% of states explicitly include engineering in their science standards, but very few teacher education programs cover engineering concepts. This creates a need for curriculum development, professional development for science teachers, and ongoing support and networking opportunities for teachers who will be tasked with teaching engineering as these standards become fully implemented. This is a particularly fitting place for the engineering education research community to step in to both share and generate knowledge about teaching engineering at a K-12 level.

## Appendix

References for science standards in all 50 states. Retrieved 12/5/17.

| | |
|---|---|
| Alabama | statepolicies.nasbe.org/college-careers/categories/content-standards/alabama-content-standards-science |
| Alaska | education.alaska.gov/akstandards/standards |
| Arizona | www.azed.gov/standards-practices/k-12standards/standards-science/ |
| Arkansas | www.arkansased.gov/divisions/learning-services/curriculum-and-instruction/arkansas-k-12-science-standards |
| California | www.cde.ca.gov/pd/ca/sc/ngssstandards.asp |
| Colorado | www.cde.state.co.us/coscience/statestandards |
| Connecticut | www.ct.gov/sde/science |
| Delaware | www.doe.k12.de.us/Page/2524 |
| Florida | www.fldoe.org/academics/standards/subject-areas/math-science/science/ |
| Georgia | www.georgiastandards.org/Georgia-Standards/Pages/Science.aspx |
| Hawaii | www.hawaiipublicschools.org/TeachingAndLearning/StudentLearning/Pages/standards.aspx |
| Idaho | www.sde.idaho.gov/academic/science/ |
| Illinois | www.isbe.net/Pages/Science-Learning-Standards.aspx |
| Indiana | www.doe.in.gov/standards/science-computer-science |
| Iowa | iowacore.gov/iowa-core/subject/science |
| Kansas | community.ksde.org/Default.aspx?tabid=5407 |
| Kentucky | education.ky.gov/curriculum/conpro/science/Pages/default.aspx |
| Louisiana | www.louisianabelieves.com/resources/library/academic-standards |
| Maine | www.maine.gov/doe/scienceandtechnology/standardsinstruction/index.html |
| Maryland | mdk12.msde.maryland.gov/instruction/curriculum/science/index.html |
| Massachusetts | www.doe.mass.edu/stem/ |
| Michigan | www.michigan.gov/mde/0,4615,7-140-28753_64839_65510-339833--,00.html |
| Minnesota | education.state.mn.us/MDE/dse/stds/sci/ |
| Mississippi | www.mde.k12.ms.us/ESE/science |
| Missouri | dese.mo.gov/college-career-readiness/curriculum/science |
| Montana | opi.mt.gov/Educators/Teaching-Learning/K-12-Content-Standards-Revision |
| Nebraska | www.education.ne.gov/contentareastandards/ |

| | |
|---|---|
| Nevada | www.doe.nv.gov/Standards_Instructional_Support/Nevada_Academic_Standards/Science/ |
| New Hampshire | www.education.nh.gov/instruction/curriculum/science/science-standards.htm |
| New Jersey | www.state.nj.us/education/cccs/2016/science/ |
| New Mexico | www.ped.state.nm.us/standards/ |
| New York | www.p12.nysed.gov/ciai/mst/sci/nyssls.html |
| North Carolina | www.dpi.state.nc.us/curriculum/science/ |
| North Dakota | www.nd.gov/dpi/SchoolStaff/Standards/ |
| Ohio | education.ohio.gov/Topics/Learning-in-Ohio/Science |
| Oklahoma | sde.ok.gov/sde/science |
| Oregon | www.oregon.gov/ode/educator-resources/standards/science/Pages/Science-Standards.aspx |
| Pennsylvania | www.pdesas.org/Page/Viewer/ViewPage/11 |
| Rhode Island | www.ride.ri.gov/InstructionAssessment/Science/ScienceStandards.aspx |
| South Carolina | ed.sc.gov/instruction/standards-learning/science/standards/ |
| South Dakota | www.doe.sd.gov/contentstandards/ |
| Tennessee | www.tn.gov/sbe/article/Science |
| Texas | tea.texas.gov/Academics/Subject_Areas/Science/Science/ |
| Utah | www.schools.utah.gov/curr/science |
| Vermont | education.vermont.gov/student-learning/content-areas/science |
| Virginia | www.doe.virginia.gov/testing/sol/standards_docs/science/index.shtml |
| Washington | www.k12.wa.us/Science/Standards.aspx |
| West Virginia | wvde.state.wv.us/instruction/NxGen.html |
| Wisconsin | dpi.wi.gov/science/standards |
| Wyoming | edu.wyoming.gov/in-the-classroom/wyoming-standards/ |

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