Are 21st century skills found in science education standards?

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Paper Goals

The goals of this paper are to examine the extent to which current prescriptive plans for science education in the US already include elements that teach 21st century skills. The 21st century skills examined include: adaptability, complex communication skills, non-routine problem solving skills, self management skills, and systems thinking, as defined by the NRC (National Research Council, 2008). The paper focuses on the National Science Education Standards (NSES), which represent the broadest single influence on science education in the US, and state science standards, which represent the most direct influence on science instruction and learning. I examine the standards from 9 different states: Iowa, Kansas, Maine, Massachusetts, New Jersey, North Carolina, South Dakota, West Virginia, and Wisconsin. These states are part of a Partnership for 21st Century Skills (http://www.21stcenturyskills.org), and thus may be particularly interested to understand how well their own state science standards cover 21st Century Skills. While containing no representation from the West or South of the US, these 9 states represent a broad range of styles of science standards, relative dominance of different industries, and general voting patterns. Although not formally analyzed in this same way, I have read state standards from many other states, and this collection of state standards seemed representative to me of the variety found in the US.

To understand why it is useful to look at national and state standards, it is important to understand what factors influence teaching in US public schools in the current NCLB context.

Figure 1. A theory of action for how national and local factors come to teaching.

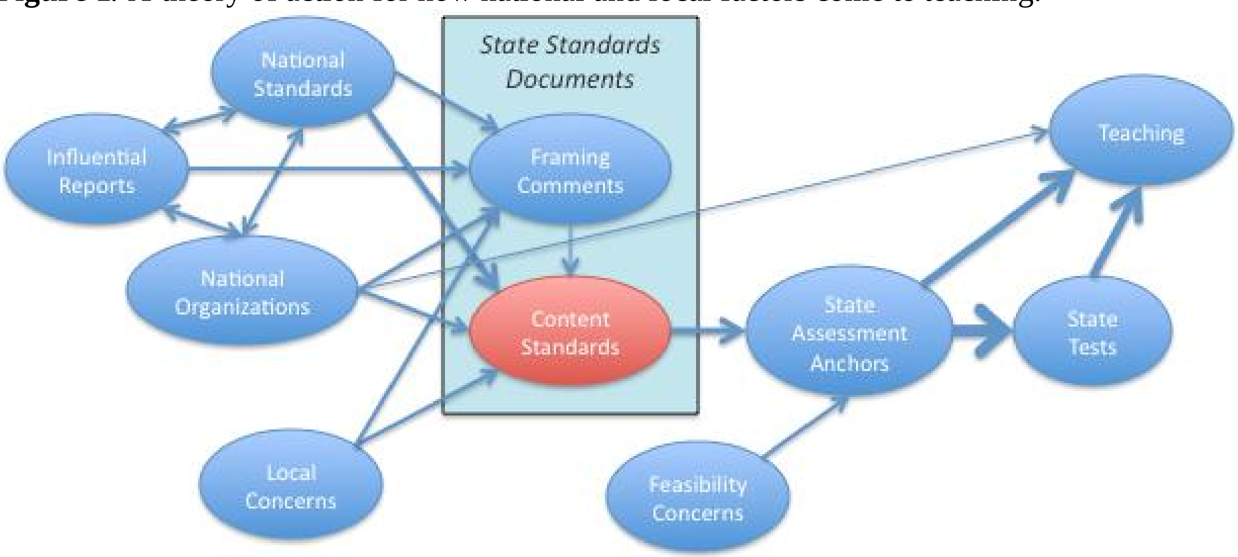


Figure 1 presents a theory of how national and local factors come together to influence classroom instruction. In the upper left of the figure, there are the national factors: influential reports such as those produced by the National Research Council and AAAS, views expressed by national organizations (such as the National Association for Research in Science Teaching, and the National Science Teachers Association), and the National Science Education Standards themselves. At the bottom left are local concerns, such as the local dominant industry, historical regional values, and local government and association leadership concerned with the standards.

The most important points from the figure are the following:

1) Teaching is most directly influence by state tests (which teachers do not directly know the precise contents of in advance) and the assessment anchors (that closely predict state test content and are presented to teachers directly).
2) State standards have two elements: a) framing comments that discuss the overall goals of the state standards, the overarching themes, and b) actual content standards that describe what skills and knowledge the students are expected to learn at particular grade levels.
3) Many state standards are heavily influenced by the national standards, but there can be huge variability across states in content standards reflecting variation in the mixture of local concerns.
4) State standards can differ significantly from state tests due to feasibility concerns: a) what standards are in fact attainable, and b) what standards are testable with available resources for test development and test grading.
5) Assessment anchors and tests can vary significantly over time, but state standards are more stable

On the basis of this theory of action, this document focuses most heavily on the state content standards, which are most proximally connected to teaching and yet are relatively stable over time. It is worth noting that an analysis of state standards is not the same as an analysis of current teaching and learning in science. The current paper is situated somewhere between an ideal situation analysis (what is the best overlap that could be possible between science instruction and 21st century skills) and an actual situation analysis (i.e., an analysis of 21st century skills learning in current science instruction).

I could have focused on state assessment anchors, which are more directly influential over teaching behaviors, but the life of such an analysis would not be very long term as those are likely to remain in flux in the coming years.

I could have focused entirely on the National Science Education Standards, which predates each of the state standards and was clearly influential in the creation of all of the examined state standards (both through an analysis of shared content with NSES and from explicit reference to that influential role in the framing comments on each standards document). However, despite this shared origin, there is in fact huge diversity across the 9 examined state standards, which I discuss in a later section. To focus on only NSES would largely mischaracterize the overlap (or non-overlap) between enforced standards through NCLB and 21st century skills.

I do not present a detailed overlap analysis with the Benchmarks for Scientific Literacy (Project 2061- American Association for the Advancement of Science, 1993), a document predating the NSES. By and large, the benchmarks contain a broader array of content than do the NSES (e.g., discussion of social sciences rather than just natural sciences, inclusion of mathematics, a deeper treatment of history of science). This greater amount of content does not generally find its way into the state science standards. For the overlapping content, some states do rely on the thematic organization of content developed in the Benchmarks, but that difference in content organization does not influence the current analysis. It is worth noting however, that engineering and design do receive greater treatment in the Benchmarks; state standards that exceed the NSES on 21st century skills do so in part from drawing more heavily on the Benchmarks than on the NSES for engineering and design content.

The remainder of this paper is organized as follows. I will provide a brief overview of the nature of the NSES and the examined state content standards. Then I will examine each of the target 21st century skills in turn, examining how well they are covered by the NSES and the state standards. The paper is organized by skill because the NSES tends to track the mid-point of the state standards, and there is incredible diversity across the skills in terms of degree over overlap. Because the listed 21st century skills actually have a number of meaningful component skills, it is possible to distinguish overlap with the whole skill and overlap with just a component skill.

Note that the overlap analysis is with the 21st century skills as they were externally defined (Levy & Murnane, 2004; National Research Council, 2008). One could have reinterpreted those skill constructs in terms of what they might have meant in a science context. But then there would be circularity to this analysis: do science skills overlap with science skills? The question on the table is: do skills of the modern workplace overlap with the current policy vision for science education in the US? That being said, this overlap analysis looks beyond superficial differences in terminology. The question is whether the underlying skills are present or not, regardless of how they are called.

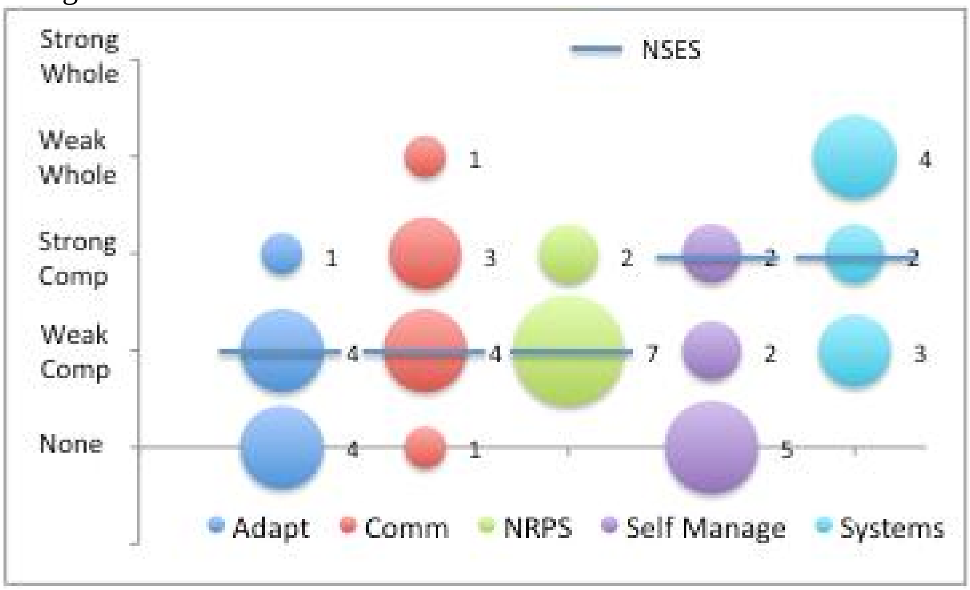
To provide a rough sense of overlap, I have created a 5-point degree-of-overlap scale shown in Table 1. Theoretically speaking, this scale aligns with an identical elements theory of learning and transfer (Klahr & Carver, 1988; Singley & Anderson, 1989; Thorndike & Woodworth, 1901). Without getting into debates about the exact form of the elements (e.g., rules, schemas, cases, or activities), it broadly assumes that 1) skills and knowledge have components, 2) learning of the components only occurs when those elements are practiced, 3) transfer can only occur when elements in the new situation overlap with elements of the old situation. Of course, there may be many additional barriers to transfer, and that is where the big theoretical debates occur (Bransford & Schwartz, 2001; Suchman, 1987).

Table 1. Scale used for evaluating degree of overlap between state standards and particular 21st century skills.

- 4 – *Strong Whole* Skill – The skill is found almost in its entirety in the standards in a strong form likely to produce high levels of performance if the standards are met
- 3 – *Weak Whole* Skill – The skill is found almost in its entirety in the standards in a weak form, either because is made optional or described vaguely
- 2 – *Strong Component* Skill – Only one or two components of the larger skill are found in the standards, but those elements are met to a high degree
- 1 – *Weak Component* Skill – Only one or two components of the larger skill are found in the standards, and even then only a weak form, either because it is made optional or described vaguely or implicit in the activities of a listed standard
- 0 – *None* – Completely absent

Figure 2 presents an overview of where the state standards and the NSES sit on this scale for each of the five 21st Century skills. Circle sizes represent how many states were at that level of overlap for each component skill.

Figure 2. A frequency count of the degree of overlap of each of the 9 selected state standards with each of the five 21st Century skills using the scale presented in Table 1. The horizontal lines indicate the rough level found in the NSES.

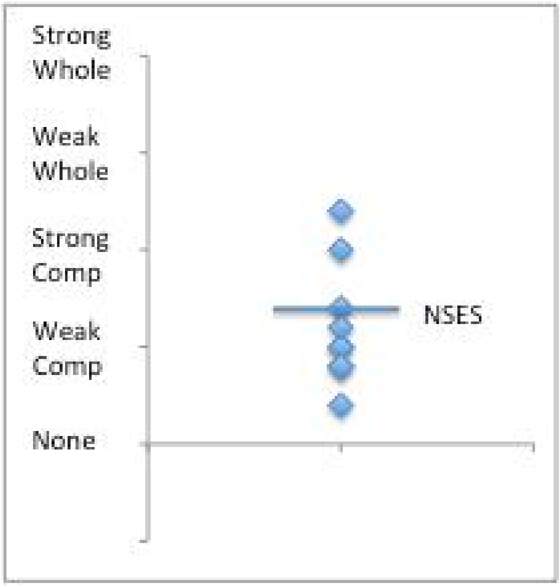


The salient observations from Figure 2 are:

1) The NSES sits in the middle of the state standards on all but self management, for which it is as high as the best overlap states.
2) Inclusion of 21st Century skills is occasionally absent, but typically in a moderate form in the NSES and state standards.
3) Only for systems thinking is there relatively high level of overlap between science and 21st century skills, and even there some states include it in a very weak form.

To foreshadow a question regarding variability overall across states, Figure 3 presents the mean level of overlap for each state, averaging across the five skills. It is clear that these 9 states different significantly, ranging for generally covering each skill at least at the strong component level to generally not covering most of the skills, even at the weak component level. The top two are West Virginia and Kansas respectively. However, beyond this aggregate analysis, this document will not single out particular states for failing to include 21st century skills.

Figure 3. Mean level of overlap of each of the 9 analyzed state science standards on the scale shown in Table 1.



Overview of the National Science Education Standards

Unlike the state standards, the NSES (National Research Council, 1996) in fact cover a very broad range of things. In addition to discussing what processes and content knowledge students should have, it also provides standards for teaching, professional development for teachers, assessment methods, science education programs, and larger learning systems. From this set, the standards regarding content (especially the process elements) and the standards regarding science teaching are particularly relevant to 21st century skills and so will be discussed here.

The content standards of the NSES can be described in terms of unifying concepts and process standards. For example, "systems, order, and organization" is a unifying theme that plays some role in all of the sciences, and it also connects to systems thinking as a skill. However, these unifying concepts are not described in great detail and tend to get lost when considering age-band-specific standards and also in the translation from NSES to state standards (especially when moving beyond the framing comments of the state standards documents).

The more traditional way of describing the NSES content standards is in terms of the 7 categories. The first four of these seven are universally found in state standards as well: science as inquiry, physical science, life science, and earth and space science. The remaining three categories are sometimes found in state standards, either as separate categories or sometimes embedded into the science as inquiry category: science and technology, science in personal and social perspectives, and history and nature of science. Of particular relevance to 21st century skills are the science as inquiry category and the science and technology category. For example, the science as inquiry category makes reference to communication skills as well as abilities for planning and selecting appropriate evidence. The science and technology categories refers to technological design, which involves identifying problems, developing and revising solutions, and communication skills.

In the NSES, the greatest overlap with 21st century skills comes in the teaching standards rather than in the content standards, especially in 3 of the 5 teaching standards. In the science teaching standards, teachers are asked to guide and facilitate learning (Standard B), which includes attention to collaboration and communication skills. Teachers are also asked to engage in ongoing assessment of student learning (Standard C), which includes guiding students in self-assessment. Finally, the standards for teaching ask teachers to "develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning" (Standard E), which includes giving students a voice in determining learning objectives, collaborating with other students, respecting diversity of ideas, and creating routines for productive formal and informal discourse. The exact overlap will be discussed in the later skill-specific sections.

The State of the 9 Examined State Standards

The main elements of state content standards are the treatment of skills or processes of science and the treatment of content knowledge. The 21st century skills of interest are skills, and thus the treatment of skills in the state standards is most relevant here. However, skills and knowledge are not entirely separable. First, skilled performance always involves a rich interplay of both skill and knowledge, and in fact one of the 21st century skills (systems thinking) involves rich conceptual knowledge that often is found in the science content knowledge standards. Second, skills and knowledge are best learned in a closely connected way, especially in science. If the state standards present content knowledge in a way that is divorced from skills, then that does not bode well for the learning of 21st century skills even if they are present in the standards.

It is important to recognize that state science standards overall have received a number of complaints. Of particular relevance here, the state standards often do not include goals of relevance to the laboratory aspects of science (National Research Council, 2006). In addition, most states include such a large number of individual topics that it appears unlikely that students can master them all, and that the diversity of individual topics hinders deep mastery of any of them (National Research Council, 2007).

Diversity of Treatment of Concepts

Across the selected 9 states, there is some variability in what content is included, at what grade level it is addressed, and at what detail the content is described. But, the main areas of content tend to track the main areas of content found in the NSES (especially the physical, life, and earth science categories). The largest variability lies in form of engagement with the content that is being sought. Some states focus almost entirely on basic understanding of core theories, ideas, and facts (e.g., "The student understands differences in structure and function among organisms and can identify the characteristics of relevant life forms"). Other states refer more to what is to be done with the knowledge (e.g., "given a chemical equation deduce the coefficients and classify the reaction type" or "Students are able to apply the kinetic molecular theory to solve quantitative problems involving pressure, volume, temperature, and number of moles of gas"). The third pattern is to integrate content knowledge standards more closely to the processes of science, such as pattern finding or phenomenon explanation (e.g., "While conducting investigations, explain the motion of objects by describing the forces acting on them"). A fourth pattern is to describe activities but not note what exactly is to be learned (e.g., "Investigate and analyze transfer of energy by work"). None of the states follow the NSES approach of describing the big ideas but not describing in what way the students must understand or apply or use the knowledge (e.g., "All animals depend upon plants. Some animals eat plants for food. Other animals eat animals that eat the plants").

Diversity of Treatment of Processes

All of the examined state standards have separate process strands, and these process strands makes some mention of a core process of scientific investigation (similar to the science as inquiry NSES category): interpreting data to form of a conclusion regarding a hypothesis (e.g., "Students are able to apply science process skills to design and conduct student investigations"). However, beyond this similarity, there are very large differences in which scientific processes are described, at what depth, and whether processes (and content knowledge) beyond just science are included. For example, some states mention instrumentation ("Select and use appropriate instrumentation to design and conduct investigations"), others consider replication ("Tests and re-tests the validity of the most promising solution), and some mention attitudes ("objectivity, openness, skepticism"). Some states have separate strands representing knowledge about the nature of science (e.g., "Describe how hypotheses and past and present knowledge guide and influence scientific investigations"), whereas others only have true process skill strands. Only one of the states directly refers to content in the process standards (e.g., "Use a control and change one variable at a time. Examples: gas laws, seed germination and plant growth, Newton's Second Law"). However, it should be mentioned that a second state mentions the processes inside the content categories ("While conducting investigations, explain the motion of objects by describing the forces acting on them").

Most notably for this paper, many (but not all) of these states include technological design processes of some form, which have considerable overlap with some of the 21st century skills of interest. In fact, some of the states included technological design at significantly greater depth than does the NSES (following the Benchmarks for Scientific Literacy), which leads to greater inclusion of 21st century skills.

Adaptability

The ability and willingness to cope with uncertain, new, and rapidly-changing conditions on the job, including responding effectively to emergencies or crisis situations and learning new tasks, technologies, and procedures. Adaptability also includes handling work stress; adapting to different personalities, communication styles, and cultures; and solving problems creatively. Finally, it includes physical adaptability to various indoor or outdoor work environments (Houston, 2007; Pulakos, Arad, Donovan, & Plamondon, 2000).

Although adapting to difficult and changing circumstances is a way of life for many children, adaptability is largely absent from the NSES and the selected state standards. The most relevant aspects come from the inquiry and technological design strands, which sometimes ask students to develop new solutions to identified problems and come to understand the perspectives of others. I divide adaptability into four components, discussed below in turn.

Ability and willingness to cope with uncertain, new, and rapidly-changing conditions on the job

Several states include technological design processes in their standards, as does the NSES. Coping with new conditions involves identifying the new problems that emerge and developing solutions for those problems. Thus, the technological design process has relevant component skills. However, most states do not make the connection between the design process and the students' own life and career. The two notable exceptions are West Virginia ("investigate, compare and design scientific and technological solutions to personal and societal problems") and Wisconsin ("show how the ideas and themes of science can be used to make real-life decisions about careers, work places, life-styles, and use of resources"). Nowhere is there a discussion of uncertainty or rapidly changing conditions.

Handling work stress

There is no direct mention of handling work stress (or any other kind of stress) anywhere. There are many sources of work stress (e.g., interpersonal conflict, task failure, uncertainty of outcomes, and task overload). The skills listed in the science standards might reduce the occurrence of some of these sources of stress, but they do not directly describe mitigation strategies.

Adapting to different personalities, communication styles, and cultures

The NSES teaching standard E makes reference to supporting collaboration, which in our more diverse population public schools will indirectly lead to learning to adapt to different personalities, communication styles, and cultures. West Virginia's standards are notable on this front ("Demonstrate the ability to listen to, be tolerant of, and evaluate the impact of different points of view on health, population, resources and environmental practices while working in collaborative groups."). Other states simply make reference to communicating ideas to others, which in practice will also involve some adaptation to be successful, but that overlap is very indirect.

Physical adaptability to various indoor or outdoor work environments

There is no direct mention of physical adaptability in any of the documents. Presumably, a variety of hands-on experience with a broad range of physical experimentation across the sciences will be relevant to this kind of physical adaptability, but that overlap is very indirect.

Complex Communication and Social Skills

> *Skills in processing and interpreting both verbal and non-verbal information from others in order to respond appropriately. A skilled communicator is able to select key pieces of a complex idea to express in words, sounds, and images, in order to build shared understanding (Levy & Murnane, 2004). Skilled communicators negotiate positive outcomes with customers, subordinates and superiors through social perceptiveness, persuasion, negotiation, instructing, and service orientation (Peterson et al., 1999).*

Components of complex communication and social skills are more strongly present in the state science standards than is adaptability. The NSES and the majority of the state standards make some reference to communication of scientific findings, often in oral and written forms, selecting appropriately what needs to be presented to be convincing. The NSES, for example, emphasizes public presentation of arguments and solutions, including explanations. In addition, NSES teaching standard E notes that teachers should "Structure and facilitate ongoing formal and informal discussion based on a shared understanding of the rules of scientific discourse".

It is worth noting that the goals of science are to be objective reasoners, rather than social negotiators, and thus some aspects of this skill are antithetical to the very cognitive view of science that the standards endorse.

I divide this skill into five component skills, discussed in detail below.

Select key pieces of a complex idea to express in words, sounds, and images, in order to build shared understanding

Many state standards are a vague on how to effectively communicate and do not make specific mention of this element. However, the Wisconsin standards do explicitly refer to trying to build shared understanding: “Present the results of investigations to groups concerned with the issues, explaining the meaning and implications of the results, and answering questions in terms the audience can understand.” West Virginia standards emphasize the organizing data to communicate both design and results: “Demonstrate the ability to utilize technology to gather and organize data to communicate designs, results and conclusions.” Overall, the Kansas inquiry standards are most detailed on this front:

> a. writes procedures, expresses concepts, reviews information, summarizes data, and uses language appropriately.
> b. develops diagrams and charts to summarize and analyze data.
> c. presents information clearly and logically, both orally and writing.
> d. constructs reasoned arguments.
> e. responds appropriately to critical comments.

Social perceptiveness

There is some mention of attending to the points of view of others, but there is really little direct mention of social perceptiveness per se. The term ‘social’ in the science standards really refers more to sociological factors (e.g., how societies perceive risks and benefits) than to inter-personal relations.

Persuasion & Negotiation

For the cognitive elements of persuasive and negotiation, the standards do regularly make mention of communication with some support scientific conclusions. As noted above, some states provide more detail, making reference to clear, logical, effective communication that responds to criticisms. However, the social elements of persuasion and negotiation are not mention, perhaps because they are viewed as antithetical to the cognitive view of scientific discourse.

Instructing

Clear communication and explanation are very important to instruction, and thus emphasis on clear communication and explanation in most of the standards is relevant to developing abilities to instruct others. However, effective instructing involves more than just clear communication and explanation (e.g., actively assessing the knowledge of others), and these other elements of instructing are not mentioned in the standards.

Service orientation

There is no direct mention of service orientation in the standards. Presumably taking on other’s problems is relevant here, and the West Virginia standards do include: “Demonstrate the ability to listen to, be tolerant of, and evaluate the impact of different points of view on health, population, resources and environmental practices while working in collaborative groups.” But even that standard is very indirectly connected to service orientation.

Non-routine Problem Solving Skills

A skilled problem-solver uses expert thinking to examine a broad span of information, recognize patterns not noticed by novices, and narrow the information to reach a diagnosis of the problem. Moving beyond diagnosis to a solution requires knowledge of how the information is linked conceptually and involves metacognition—the ability to reflect on whether a problem-solving strategy is working and to switch to another strategy if the current strategy isn't working (Levy & Murnane, 2004). It includes creativity to generate new and innovative solutions, integrating seemingly unrelated information; and entertaining possibilities others may miss (Houston, 2007).

On the whole, non-routine problem solving was only found at a relatively weak level across the board in state standards and the NSES. Elements of non-routine problem solving can be found within inquiry and technological design processes. However, the inquiry and technological design can be relatively scripted and routine, and those forms provide only weak support for non-routine problem solving.

It is important to note that some of the components listed in non-routine problem solving skills (the last two is my list below) are the result of domain expertise; that is, some of the components are the inevitable consequence of large amounts of practice in a domain and are not really general skills to be learned in one context and applied across many domains.

I divide non-routine problem solving into six component skills, which I discuss below.

Narrow the information to reach a diagnosis of the problem

Across the board, science standards include significant coverage of problem diagnosis, but in different ways. In a few cases, inquiry standards make clear reference to diagnosis skills (e.g., Iowa: "Selects best evidence" and Kansas: "analyzes their explanation by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models have the greatest explanatory power"). Sometimes the information selection skills are listed under inquiry, but could apply equally well to inquiry or design (e.g., New Jersey: "Develop strategies and skills for information–gathering and problem-solving, using appropriate tools and technologies"). In yet other cases, the steps of technological design are specified in sufficient detail to include diagnosis (e.g., North Carolina: "Identify problems appropriate for technological design; Develop criteria for evaluating the product or solution; Identify constraints that must be taken into consideration").

Ability to reflect on whether a problem-solving strategy is working and switch to another strategy if the current strategy isn't working

Revision of strategies has some similarities to revision of theories (i.e., reflection on existing adequacy, decision to change), and the NSES and several state standards include some discussion of revision of theories on the basis of contradictory evidence (e.g., Kansas: "based on their results, students consider modifications to their investigations."). Interestingly, some states simply require noting inadequacies of limitations of theories rather than noting a requirement to change to better theories. Similarly, redesigning a product to improve it or adapt it to new needs involves moving beyond an existing solution approach, and deciding a new approach is required. A few states emphasize this aspect of technological design (e.g., Maine: "Students use a systematic process, tools and techniques, and a variety of materials to design and produce a solution or product that meets new needs or improves existing designs").

Creativity to generate new and innovative solutions

Creativity is an important element of science and technological design, although this 21st century skill component is more closely related to creativity in design. A few states only emphasize the evaluation rather than generation aspects of science and design, but most states make mention of the generation of new theories (e.g., West Virginia: “apply skepticism, careful methods, logical reasoning and creativity in investigating the observable universe”) or new designs (e.g., e.g., Wisconsin: “Propose a design (or re-design) of an applied science model or a machine that will have an impact in the community or elsewhere in the world”) in their standards.

Integrating seemingly unrelated information

The NSES and state standards do not make direct mention of this integration of very diverse information. However, both science and design involving integration of a variety of kinds of information. Whether that information is seemingly unrelated is likely to be very subjective.

Recognize patterns not noticed by novices

Pattern recognition is a simple element of expertise. It comes from exposure to many problems in a domain (Chase & Simon, 1973; Gobet & Simon, 1996). Those patterns are specific to a domain of expertise. There is no obvious way to train this domain-specific pattern recognition in a domain independent way. On the other hand, pattern analysis is a core aspect of scientific reasoning. Some very general features of organizing data to look for patterns is mention in several state standards (e.g., Iowa: “Interprets symbols and data from a table and graph”).

Knowledge of how the information is linked conceptually

Conceptual linkages between knowledge is also a direct result of expertise that comes from exposure to many problems in a domain (Chi & Koeske, 1983). This knowledge is domain specific. However, the strategy of organizing and reviewing information in order to build an overall theoretical understanding of the materials is a core element of scientific reasoning (e.g., West Virginia: “formulate scientific explanations based on historical observations and experimental evidence, accounting for variability in experimental results”).

Self Management Skills

> *Self-management skills include the ability to work remotely, in virtual teams; to work autonomously; and to be self motivating and self monitoring. One aspect of self-management is the willingness and ability to acquire new information and skills related to work (Houston, 2007).*

Self-management skill is the one instance in which the NSES sit noticeably above most state standards with respect of coverage of 21st century skills. The majority of the state standards do not include much coverage of self-management skills. I divide self management skills into six component skills, discussed below.

Ability to work remotely, in virtual teams; work autonomously

The NSES and a few states make some mention of the ability to work collaboratively, which is presumably related to the ability to work in virtual teams (e.g., West Virginia: “Demonstrate the ability to listen to, be tolerant of, and evaluate the impact of different points of view on health, population, resources and environmental practices while working in collaborative groups"). However, the solitary aspect is not explicitly discussed.

Work autonomously; Self motivating

Only the NSES refers directly to working autonomously, as in Teaching standard B: "Challenge students to accept and share responsibility for their own learning".

Self motivating

Self-motivation is not discussed directly in the NSES and state standards. However, the NSES refers indirectly to self-motivation in Teaching standard E: "Enable students to have a significant voice in decision about the content and context of their work."

Self monitoring

Some aspects of self monitoring are found in the NSES and in two of the state science standards. In Teaching standard C of the NSES, teachers are directed to "guide students in self-assessment". Kansas refers to another aspects of self-monitoring: "Evaluates personal preconceptions and biases with respect to his/her conclusions". West Virginia includes evaluation and tolerance of different points of view, which is related to self-monitoring: "Demonstrate the ability to listen to, be tolerant of, and evaluate the impact of different points of view on health, population, resources and environmental practices while working in collaborative groups."

Willingness and ability to acquire new information related to work

Although not discussed directly in those terms, one can take the gathering of new information to inform scientific theories as relevant to acquiring new information related to work. Thus, all science standards will make some connection to this 21st century skill. The few states that specifically mention openness show the strongest connections. Kansas is most explicit in these details:

a. engages in discussions that result in the revision of his/her explanation.
b. analyzes their explanation by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models have the greatest explanatory power.
c. evaluates personal preconceptions and biases with respect to his/her conclusions.
d. based on their results, students consider modifications to their investigations.

Willingness and ability to acquire new skills related to work

The state science standards make no direct reference to acquiring new skills as a skill. In contrast, the NSES note as part of Teaching standard E: "Enable students to have a significant voice in decision about the content and context of their work and required students to take responsibility for the learning of all members of the community."

Systems Thinking

The ability to understand how an entire system works, how an action, change, or malfunction in one part of the system affects the rest of the system; adopting a "big picture" perspective on work (Houston, 2007). It includes judgment and decision-making; systems analysis; and systems evaluation as well as abstract reasoning about how the different elements of a work process interact (Peterson et al., 1999).

Some aspects of systems thinking are found in the NSES and all state science standards. Systems is a unifying theme across all the major scientific disciplines. Moreover, systems thinking is an important aspect of technological design. However, states vary in the extent to which they highlight the systems features in their content standards, and in the extent to which they note systems aspects of technological design. I discuss two main aspects of systems thinking: systems analysis and systems decision making.

Systems analysis

All of the examined science standards made some reference to the analyzing aspects of a system in at least one context (e.g., New Jersey in the life sciences: "Describe the basic functions of the major systems of the human body including, but not limited to: digestive, circulatory, respiratory, nervous system, skeletal, muscular, reproductive systems; Massachusetts in technologies: "Identify and describe three subsystems of a transportation vehicle or device, i.e., structural, propulsion, guidance, suspension, control, and support"). A few states make mention of systems as part of unifying themes (following the NSES closely on the choice of unifying themes), but then make little mention of systems in any of the particular content standards.

Some states also made reference to systems analysis in design (e.g., New Jersey: "Identify the basic components of a technological system: input; process; output; and feedback").

Systems decision making

Science standards made more uneven mention of systems thinking as part of decision making (e.g., West Virginia: "predict the effects of human activities on biogeochemical cycles of matter and energy in the biosphere over time," Maine: "Analyze a system using the principles of boundaries, subsystems, inputs, outputs, feedback, or the system's relation to other systems and design solutions to a system problem," and New Jersey: "Assess the impact of human activities on the cycling of matter and the flow of energy through ecosystems"). Interestingly, the NSES make little mention of systems in designed objects.

Overlap with other Science Education Reform Reports

Although the primary focus of this document is on science standards, it is also interesting to note the overlap (or non-overlap) of 21st Century Skills with recent reports that call for science education reform. I present brief comments on two recent reports.

America's Lab Report: Investigations in High School Science (National Research Council, 2006)

Focusing on high school science, America's Lab Report notes the following goals for science laboratories (p. 53):

- *Mastery of subject matter,*
- *Developing scientific reasoning,*
- *Understanding the complexity and ambiguity of empirical work,*
- *Developing practical skills,*
- *Understanding the nature of science,*
- *Cultivating interest in science and interest in learning science, and*
- *Developing teamwork abilities.*

Each of these has relatively straightforward content, except perhaps one: 'practical skills' in the context of laboratory science goals refers to equipment use goals, not a broader set of practical real world skills found in the 21st Century skills list. While current high school science labs will have relatively little attainment of these goals, one could still ask the question: suppose high school science labs were reformed to attain all of these goals to high levels in the majority of kids, would we also seek gains in 21st Century skills?

Table 2 presents a summary of the overlap between these goals and the 21st Century Skills. On the basis of this overlap analysis, the answer that transfer question is yes, at least to a modest extent. All five 21st Century skills overlap to at least a small extent with at least two of the high school science lab goals. Communication skills would likely see the greatest benefit, with students have considerably more experience with teamwork situations, coming to use scientific discourse rules to solve problems (at least those of an inquiry nature). At the same time, it is important to note that at least three of the high school science lab goals have no clear overlap with 21st Century skills—to the extent that reform focuses on those goals alone, we will not expect to see any benefit for 21st Century skills.

Table 2. Alignment between Goals of High School Science Labs and 21st Century Skills, using the overlap scale from Table 1.

High School Lab Goal	Adaptability	Communication skills	Non routine Prob Solve	Self Manage	System Thinking
Mastery of subject matter	0	0	0	0	1
Developing scientific reasoning	1	2	1	1	0
Understanding the complexity and ambiguity of empirical work	1	0	1	0	1
Developing practical skills	0	0	0	0	0
Understanding the nature of science	0	0	0	0	0
Cultivating interest in science and interest in learning science	0	0	0	0	0
Developing teamwork abilities	1	2	1	1	0

Taking Science to School: Learning and Teaching Science in Grades K-8 (National Research Council, 2007)

An NRC report one year later focused on elementary and middle school science, but this time examining all science instruction rather than just that occurring in laboratory format. That report highlighted four strands of scientific proficiency (p. 37):

1. *Know, use, and interpret scientific explanations of the natural world*
2. *Generate and evaluate scientific evidence and explanations*
3. *Understand the nature and development of scientific knowledge*
4. *Participate productively in scientific practices and discourse*

These four strands have considerable overlap with high school science lab goals 1,2,5, and 6, although they are organized in slightly different ways. Although not obvious, note that the fourth strand also includes motivation elements, and thus captures the 'cultivating interesting' high school goal. These K-8 strands do however leave out several of the high school science goals (complexity of empirical work, developing practical lab skills, and developing teamwork skills). As only the last of those three is relevant to 21st century skills, the total picture of overlap with 21st Century skills is partially but significantly reduced. At the same time, all five 21st Century skills remain represented, if perhaps in only weak form (see Table 3).

Table 3. Alignment between K-8 Science Proficiency Strands (NRC, 2007) and 21st Century Skills, using the overlap scale from Table 1.

K-8 Science Proficiency Strands	Adaptability	Communication skills	Non routine Prob Solve	Self Manage	System Thinking
Know, use, and interpret scientific explanations of the natural world	0	0	0	0	1
Generate and evaluate scientific evidence and explanations	1	1	1	1	0
Understand the nature and development of scientific knowledge	0	0	0	0	0
Participate productively in scientific practices and discourse	1	2	1	0	0

Conclusions

From a policy perspective, this overlap analysis presents a glass half full: current policy in science education calls for student learning that generally does not full encompass 21st century skills, but does presents a useful foundation for learning the 21st Century skills. In addition, there is considerable variability across state standards in inclusion of 21st Century skills, which present more proximal pressure on student learning that do the national standards, suggesting that one would expect unevenness is student learning of 21st Century skills across states. If states are interested in changing their science education standards to include more of a foundation for 21st Century skills, the current analysis suggests what kinds of science standards are most relevant (e.g., by paying particular attention to West Virginia and Kansas).

It is important to note the difference between laying a foundation and fully learning a skill. If students are expected to enter the workforce with the full set of 21st Century skills in hand, then considerable training in these skills is required beyond the experiences called for in the science classroom. For such additional training, attention to the details of each of the five skills is required. That is, it is extremely important not to stop with a superficial 'ragu sauce' analysis of curricula in which standards are 'met' by any content at all that falls under the larger category. For example, the full set of communication skills are NOT met by simply having a few activities that teach SOME communication skills.

Although the prediction from this standards document analysis is that science classrooms will not fully bestow 21st Century skills on students, that does not mean could not. Training for 21st Century skills *could* take place in the science classroom if the science classroom were expanded to include attention to these skills. Or said another way, there is nothing incommensurate between the 21st Century skills and those already being requested in the science classroom. For example, science classrooms tend to focus narrowly on a certain range of adaptability and communication skills, if at all. But the broader set of adaptability and communication skills could be addressed in a science context.

Finally, it is important to acknowledge two huge gulfs between policy and reality. First, there is the gulf between what the current science standards include and what state science tests actually include. This gulf is particularly large for skills because it is very hard to test skills using multiple choice tests in ways that do not boil down to mostly measuring reading skill. Thus, I would expect that many of the science standards highlighted as overlapping with 21st Century skills in the current analysis of state standards are largely untested in their state tests.

Second, just because it is tested does not mean it is learned. As low as the national achievement is on reading and writing state tests, it is even lower in science! Thus, changing science standards and tests alone is unlikely to produce high performance on the 21st Century skills. For that, a more systematic reform of science education teaching and curricula will be required.

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