OPEN ACCESS

Research Article

American Journal of Science Education Research

A Continuum of Students' Science Identity Strengths

William J. F. Hunter[a]* and Kevin Diaz[b]

[a]*Department of Chemistry, Illinois State University, Normal, Illinois, USA.*
[b]*Blanson Career and Technical Education High School, Houston, Texas.*

***Corresponding author:** William J. F. Hunter, Department of Chemistry, Illinois State University, Normal, Illinois, USA. Tel: 61790-4160.

Received: November 21, 2022; **Accepted:** November 24, 2022; **Published:** November 30, 2022

Citation: Hunter WJF and Diaz K (2022) The Next Generation Science Standards and High School Chemistry: Pre-pandemic Steps of Implementation. American J Sci Edu Re: AJSER-101.

Abstract

Since 2012 schools across the Unites States have been adopting the Next Generation Science Standards (NGSS) to change the content and manner in which science is taught. This new approach is comprehensive and requires teachers and students to re-shape the organization and approach to many long-standing practices. For chemistry educators the NGSS, based upon Science and Engineering Practices, Disciplinary Core Ideas; and Cross Cutting Concepts, are an attempt to have students memorize less, make more sense of phenomena, connect science to mathematics and language arts, and apply knowledge in context. Over 70% of USA students are in schools that are adopting the NGSS and their implementation over the past few years and into the future should have significant impact upon the chemistry preparation of entering American college students over the next decade. This report describes the structure and intent of the NGSS and some high school chemistry lessons initial implementation of them. Using classroom visits and interviews from 2016 to 2022 the authors describe some introductory practices of those high school teachers and some implications for college and university chemistry educators over the next decade as students move through the American educational system.

Keywords

Chemistry, Next Generation Science Standards, Chemistry Education, High School, USA.

Introduction

As some of you are aware, over the past ten years public elementary and secondary schools across the Unites States have been trying to change the way science instruction is conducted and outcomes are achieved. This new approach is comprehensive and requires teachers and students to re-shape the organization and approach to many long-standing practices. The Next Generation Science Standards (NGSS) are an attempt to have students memorize less, make more sense of phenomena, connect science to mathematics and language arts (the Common Core), and apply knowledge in context. The design and implementation of the NGSS are grounded in research and with the aims of reaching more students and helping all students to have a more profound science experience. You can learn much more about the rationale, and development elsewhere (see for example: Next Generation Science Standards (NGSS Lead States, 2013) [1], The National Science Teachers Association (National Science Teachers Association, 2021) [2], or the National Association for Research in Science Teaching (National Association for Research in Science Teaching, 2014) [3] but overall The American Chemical Society Division of Chemical Education recognized, "… the Next Generation Science Standards, including their basis in research on teaching and learning, their formulation as performance standards, and their basis in the NRC framework and its dimensions of Science and Engineering Practices, Disciplinary Core Ideas, and Cross Cutting Concepts. We endorse the Standards as a document that is broadly applicable as a basis for K-12 science instruction." [4].

In this article, we want to share some changes that being made by teachers which will impact the students that enter your college chemistry classroom over the next few years. These changes were identified via classroom visits and interviews with teachers enrolled in a graduate chemistry education program during 2016-2020.

Aims

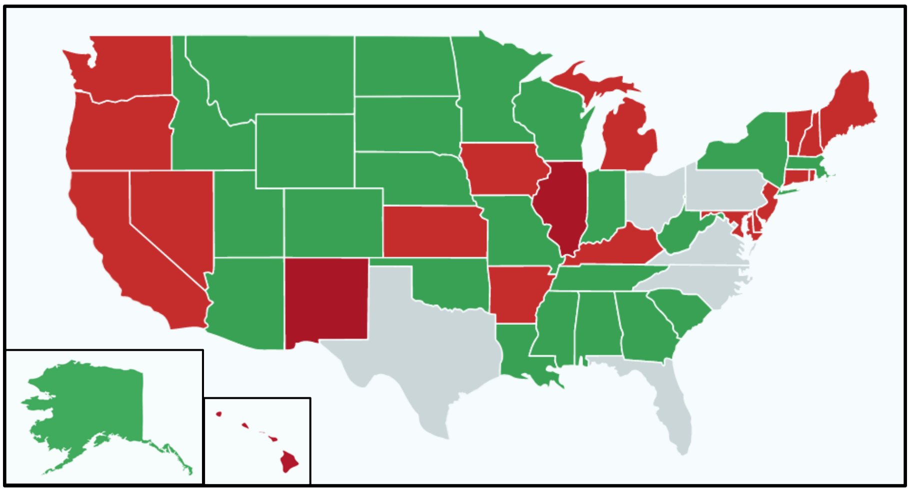
In this article, we want to share some changes that being made by teachers which will impact the students that enter your college chemistry classroom over the next few years. In doing so, we hope that you will be better prepared for classroom goals and activities with your incoming students.

Method

Between the years of 2016 and 2020 (prior to the COVID-19 pandemic) we visited classrooms of chemistry teachers in their beginning stages of NGSS implementation. Interviews with teachers and examining their classroom lessons and artifacts were used to discern their level of understanding and implementation at the time.

Results / Discussion

Who is implementing the NGSS?



Forty-four states (representing 71% of U.S. students) have education standards influenced by the Framework for K-12 Science Education and/or the Next Generation Science Standards.

Twenty states and the District of Columbia (in red above representing over 36% of U.S. students) have adopted the Next Generation Science Standards (NGSS). The 20 states are Arkansas, California, Connecticut, Delaware, Hawaii, Illinois, Iowa, Kansas, Kentucky, Maine, Maryland, Michigan, Nevada, New Hampshire, New Jersey, New Mexico, Oregon, Rhode Island, Vermont and Washington. Twenty-four states (in green above representing 35% of U.S. students) have developed their own standards based on recommendations in the NRC Framework for K-12 Science Education. The 24 states are Alabama, Alaska, Arizona, Colorado, Georgia, Idaho, Indiana, Louisiana, Massachusetts, Minnesota, Mississippi, Missouri, Montana, Nebraska, New York, North Dakota, Oklahoma, South Carolina, South Dakota, Tennessee, Utah, West Virginia, Wisconsin, and Wyoming [5].

What is NGSS?

The NGSS are based on the National Research Council's *Framework for Science Education* that is composed of three strands: *Disciplinary Core Ideas, Crosscutting Concepts,* and *Science and Engineering practices*. *Disciplinary Core Ideas* (DCIs) are broad ideas that articulate the way traditional STEM disciplines are organized; the DCIs describe important concepts, and are developed over time throughout K–12. The DCIs as written in the framework could be addressed in courses from kindergarten to graduate school. For example, the first physical science core idea—PS-1, Matter and its Interactions—is guided by the question "How can one explain the structure, properties, and interactions of matter?" The development of PS-1 begins in the early elementary years with "matter exists as difference substances as exhibited by their observable properties" and progresses through high school where "the sub-atomic model and interactions between electric charges can be used to explain interactions of matter." Although the NGSS doesn't address undergraduate and graduate education in chemistry and physics, you can imagine that PS-1 could be further developed into quantum mechanics, density functional theory, and other intramolecular and intermolecular force topics as they "explain the structure, properties, and interactions of matter." These learning progressions are based upon our best, research-based understanding of what students can learn at various developmental stages along the K-12 continuum [4,6].

Crosscutting Concepts are ideas that extend across traditional disciplines and help show the connections between those disciplines. Within the traditional science disciplines: *Cause and Effect, Patterns, Energy and Matter, Structure and Function, Systems and Systems Models, Scale, Proportion, and Quantity,* and *Stability and Change* are important concepts that connect those disciplines together. Developing these crosscutting concepts allows students to develop a coherent understanding of science concepts.

Science and Engineering Practices are those inquiry activities in which scientists and engineers and those behaving in a scientific way are engaged. In the *Framework for Science Education*, the NRC, designated the group of Science and Engineering Practices to include the mechanisms used by scientists and engineers to understand and explore the natural world and to solve problems within it. These mechanisms include traditional scientific activities, such as: *planning and monitoring experiments; analyzing and interpreting data; engaging in argument from evidence*; *developing explanations; developing and using models*; and *using mathematical thinking*.

When the DCIs, CCs, and SEPs are combined into standards, they are written as a set of "*performance expectations*" in which the three strands from the framework are tightly interconnected, rather than separate content and inquiry standards. Hence, each performance expectation contains disciplinary knowledge (DCI) developed via a science and engineering practice (SEP) and considered in light of a crosscutting concept (CC). In terms of student achievement, each standard has a set of performance and assessment expectations which both guide and limit what the student and teacher are expected to achieve in each grade band.

In high school physical science (HS-PS1) Matter and its Interactions, there are eight performance expectations. The first of which describes students who demonstrate understanding as being able to:

Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

[Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] [*Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.*]

Note that the clarification statement and assessment boundary give guidance for what should be achieved at the high school level. Those clarifications and assessments would, of course, be different at the elementary and middle school level. If you wanted to extend the NGSS into undergraduate and graduate levels you could write your own clarifications and assessment boundaries for your courses and what you expected your students to be able to predict and explain using the periodic table. The complete NGSS set of performance expectations for PS1 (Matter and its Interactions) can be seen at the NGSS website for HS-PS1 Matter and its Interactions (Achieve, 2013).

Looking at the third standard **HS-PS1-3**.:

Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

This standard contains the science practice of planning investigations, the crosscutting concepts of patterns and scale, and the disciplinary core idea that structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. The DCI, SEP, and CC all form part of the performance expectation in such a way that it cannot be achieved without all parts of the standard being met. This design helps teachers, curriculum developers, and assessment developers integrate lessons aimed at supporting the concept of macroscopic properties being dependent upon molecular level interactions.

There are many ways in which a high school chemistry teacher could plan lessons to achieve this expectation. It might include planning an observation/measurement and ordering of the melting points achieved as heat is added to various substances (salts (NaCl, $CaCO_3$); lipids/organics (butter/margarine, wax, gasoline, oils); sugars (syrups, brown sugar, white sugar); metals (Fe, Cu, aluminum foil), and having the students relate their observations back to what they have learned about the types of elements present and the bonding and structure of the elements and molecules. Another teacher might lead to this investigation by having students induce electrostatic forces using classical hair/wigs, balloons, and other materials.

Irrespective of the way in which teachers try to develop students' ability to achieve the performance expectation; one central focus of the NGSS is to find a phenomenon that is interesting and motivating to students. This phenomenon and the students' interest in it drives the development of three dimensions of the performance expectation.

In the example above, the phenomena might be phrased in the form of a question, "When I am frying, why do some foods melt and others not?" or "Why do some clothes stick together when they come out of the dryer?" (Concord Consortium, 2022) [7].

In contrast, many chemistry courses have traditionally taught intermolecular forces with teachers explaining structure and shape of molecules, showing graphs of melting point linked to periodic trends, conducting demonstrations of liquids responding to and ignoring external electrostatic forces. All of these steps could lead students to "infer the strength of electrical forces between particles," but would not necessarily lead to the science practice of planning the investigation to gather data nor to the focus on Patterns and Scale. Perhaps for you – an expert in science, chemistry, and education – those things are obviously to be included in meaningful lessons, but within the NGSS; all three dimensions are now explicit within the performance expectation for the students and hence for the teacher. How the teacher achieves those goals is still very flexible and requires significant skill, but the goal and standard is clear.

Finally, the clarification statement for **HS-PS1-3** reads in part: [Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.] [*Assessment Boundary: Assessment does not include Raoult's law calculations of vapor pressure.*]. These Emphases and Assessment Boundaries help the teacher (and student) know what should be taught in courses, and what is to be expected in assessments.

Almost no one has a handle on how to teach all of these aspects simultaneously. At best, over the past ten years since the adoption of NGSS, science and chemistry teachers have begun the process of experimenting with what they can and should be doing in their classrooms. Furthermore, the nature of NGSS is such that as a K-12 progression, it relies upon students and teachers in earlier grades making progress on their part. So given that not all states have adopted, nor all schools are implementing the same way, and not all teachers have the same insights and abilities, and that it will be twelve years until the current Kindergarten students reach college; there is, and will be, significant variability in what your current and near-term future students will have experienced prior to arriving in your college chemistry classes.

Even given those caveats; chemists, especially those that teach beginning chemistry students at the collegiate level, should have some knowledge of how secondary chemistry teachers are changing their high school instruction.

Here are a few examples of the ways in which high school teachers are responding to this NGSS challenge. In 2016-2020 (prior to the pandemic), we were able to visit several classrooms as they began the process of adopting and adjusting their chemistry courses to NGSS. In each case the teachers began with their lowest level chemistry class – what most people would refer to as first year or regular chemistry. For the most part the teachers had made very minor changes as they had taken the names of the SEPs and the CCs and made a list in their curriculum notes and a poster for the classroom wall. First attempts to integrate NGSS into existing experiments and demonstrations began with these lists of CCs and SEPs. During the post-experiment debrief teachers would ask students to look at the lists of SEPs and CCs and make a claim about which practices and concepts were part of the recently completed activity. If the laboratory exercise included some student choices, then perhaps students would identify "Planning and Carrying Out Investigations." The unstated, but perhaps understood goal, was that if the students made similar and repeated claims throughout the chemistry course, the students would internalize; in general, that often, scientists and engineers plan and carryout investigations or that continued attention to *Patterns* or *Models* or *Energy and Matter* would result in students recognizing them as being concepts that unify many aspects of science and engineering. Viewed positively, these teachers were attempting to incorporate the SEPs and CCs into their teaching because they saw the value in it despite very little professional development being available to them. These teachers struggled to know how to teach and integrate the SEPs and CCs; the students were at best inferring meaning that matched the words in the NGSS descriptions.

By 2018, those same teachers had made some more profound progress on their implementation of NGSS over the course of the academic year. When asked, several of them could explain that they had expectations for changes in depth of experimentation in the SEPs and depth of explanation of the CCs expected throughout the year with which they had the students. For example, in *Planning and Carrying out Investigations*, several teachers who worked together indicated that at the beginning of the year in a first chemistry course, students might be able to only carry-out a teacher-planned investigation, but that later in the year, some of the procedure would be determined by the student (or groups of students), and later in the course, even less would be determined by the teacher. Having students take ownership of procedures is not new in chemistry or science education (see science fairs, guided-inquiry, open inquiry, etc.), but these teachers (either as a result of professional development or their own insight) were beginning to see how to incorporate longitudinal development of NGSS into their courses.

In another similar vein with regard to the cross-cutting concept *Stability and Change*. In HS-PS1-6, the expectation is that students can "refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium." In 2016; the experienced teachers of first year chemistry courses were barely able to identify a core chemistry idea that related to *Stability and Change* despite the hint of an accompanying clarification statement pointing to Le Chatelier's Principle*.* Two years later, however, examples of meaningful attempts included specific equilibrium reactions which those teachers used to demonstrate stresses and changes in equilibrium as a response (using classical reactions of $[Fe^{+3}] + [SCN^{-}] \Leftrightarrow [FeSCN^{+2}]$) and reaction rate explorations (using particle size, temperature, and catalysis) as a way to link to reactions producing more products quickly.

As you might begin to infer from these two examples, teachers are making progress in better meeting the intent of the NGSS. This progress is in part due to professional development for NGSS that over the past few years has included, focusing on the three dimensions of NGSS and trying to give much more equal time and effort to them. So called three-dimensional learning has been led by trying to find central phenomena that teachers could use to engage students in studying science or chemistry. Sometimes the central phenomena are expressed in the form of a question, "If you wanted to give a child under the age of 10 a piece of bubble gum with the least amount of sugar, which bubble gum would you give them? or "Why do some things stick together and other things don't?" Robust lessons are being developed and shared by consortia across the nation. (See for example: The Concord Consortium (Concord Consortium, 2022) [7] and NSTA's NGSS Resource Finder (National Science Teachers Association, 2022) [8]. In our home state, the Illinois State Board of Education (ISBE) is committing significant resources to writing state assessments that match the goals of NGSS. Those resources have teachers from across the state working in tandem to write assessments which will then be linked to classroom activities to help drive instruction towards meeting the NGSS. Once complete ISBE also intends to those assessment resources nationwide [9].

By 2020, teachers were able to reflect upon a few years of experience and begin to more profoundly implement the NGSS. Teachers were able to describe some novel activities and to begin to respond to students' actions in the knowledge of what had happened in previous years. The teacher's reports of classroom activities included new phenomena that they used to start lessons and units (for example: rocket fuel ignition and slow temporal views of matches burning), and examples of how those phenomena link to SEPs and CCs.

Conclusion

Irrespective of how they are implemented one goal for the NGSS is that they are a set of minimum expectations towards which every student should be making progress. As a minimum set of expectations, some students should be able to achieve them earlier than others. Extrapolate a few students to a few hundred in an educationally aggressive environment and it is easy to see that some schools will be able to justify attainment of the NGSS by 10th or 11th grade. So, some school systems will have "NGSS science" classes that students complete by the 10th or 11th grade and they will be able to offer very traditional *Advance Placement, Honors*, or *Accelerated* classes to students in 11th and 12th grade. So, college chemistry instructors should expect to continue to see wide variability in the chemistry preparation of their students over the next decade and beyond.

There are four important things to note at this point. First, there is significant intellectual load on the part of students to understand all that is encompassed in each of the standards. Second, there is a significant challenge for the teacher to teach beyond the disciplinary core ideas, and continually link to and come back to the crosscutting concepts, and to engage the student with the science and engineering practices. Third, there is significant freedom on the part of teachers and schools in developing curriculum that addresses and teaches the standards. (For instance, in PS1-1 a full range of didactic and student-centered approaches can be incorporated: POGIL activities, traditional labs, simulations, demonstrations, and teacher-led presentations can all form part of the curriculum.) The novel additional challenge for teachers is to integrate the SEPs and CCs in a seamless and meaningful way. Fourth, chances are, as a professional chemist, you have developed an understanding of many of the crosscutting concepts and science and engineering practices and can see them in your daily and professional life. (As you likely know, however, you are in the minority and previous generations of students have not developed the connections between their school science experience and these concepts and practices.)

The Next Generation Science Standards are a broad attempt to have students understand traditional science content (DCIs) while integrating science practices (SEPs) and making connections to wider scientific principles (CCs). They are expected memorize less, make more sense of phenomena, connect science to mathematics and language arts, and apply knowledge in context. If the bulk of your students arrive in your classes from NGSS adoptive states, you should increasingly be able to point to these standards as being part of your students' preparation over the next decade. The National Science Teachers Association has tried to identify example lesson units that exemplify the types of teaching that will help achieve the NGSS (National Science Teachers Association, 2022) [8].

Appendix:

Finally, we want to list the expectations for chemistry at the end of high school. These are statements for what every student entering college and university courses should be able to do. Students who demonstrate understanding can:

HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.]

[Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.]

HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.]

[Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]

HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. [Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.]

[Assessment Boundary: Assessment does not include Raoult's law calculations of vapor pressure.]

HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. [Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.]

[Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.]

HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.]

[Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.]

HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium* [Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.]

[Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]

HS-PS1-7. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.]

[Assessment Boundary: Assessment does not include complex chemical reactions.]

HS-PS1-8. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay. [Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.]

[Assessment Boundary: Assessment does not include quantitative calculation of energy released. Assessment is limited to alpha, beta, and gamma radioactive decays.]

Acknowledgement

Institutional Review Board Approval. Some information from this article was obtained under approval by the Institutional Review Board of Illinois State University for research with human subjects #[871109-3] Critical Factors in Graduate Chemical Education and in K-12 Integrated STEM Education Programs. Gratitude is extended to those teachers in 2016, 2018, and 2020 who were willing to share their classrooms and experiences with the authors.

References

1. NGSS Lead States. (2013) *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press. Improving Science Education Through Three-Dimensional Learning. Retrieved September 7, 2022 from https://www.nextgenscience.org/three-dimensions.
2. National Science Teachers Association. (2021). *Improving Science Education Through Three-Dimensional Learning.* Retrieved September 7, 2022, from https://ngss.nsta.org/About.aspx.
3. National Association for Research in Science Teaching (2014) *NARST Blog*. Supporting The Implementation of NGSS Through Research: Curriculum Materials. Retrieved August 6, 2022, from https://narst.org/blog/ngss-curriculum.
4. Cooper, M. M. (2013). Chemistry and the Next Generation Science Standards. *Journal of Chemical Education*, *90*(6), 679-680. Retrieved August 6, 2022, from https://doi.org/doi.org/10.1021/ed400284c.
5. National Science Teachers Association. (2021). Quality Examples of Science Lessons and Units. Retrieved September 7, 2022 from https://www.nextgenscience.org/resources/examples-quality-ngss-design
6. National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press Retrieved September 6, 2022. http://www.nap.edu/openbook.php?record_id=13165
7. Concord Consortium (2022) High School: Interactions Unit 1 - Why do some clothes stick together when they come out of the dryer? Retrieved September 7, 2022 from https://www.nextgenscience.org/resources/high-school-interactions-unit-1-why-do-some-clothes-stick-together-when-they-come-out
8. National Science Teachers Association. (2022). NSTA Classroom Resources. Retrieved September 7, 2022 from https://ngss.nsta.org/classroom-resources-results.aspx?CoreIdea=1
9. Brown, D.L. (2022) Division of Assessment and Accountability, Illinois State Board of Education, Springfield, IL. Personal communication.