Safety and the Next Generation Science Standards

NSTA Safety Advisory Board White Paper

A Call to Action

In 2013, Achieve, Inc. released the final draft of the Next Generation Science Standards (NGSS) as an effective research-based approach to providing all students access to a high-quality science education. This approach will help to prepare students to enter college, to embark on a career of their choosing, and to make informed decisions about issues relating to the global environment, health care, or space exploration (NGSS Lead States, 2013). The National Science Teaching Association (NSTA) has recommended that state education agencies (SEA) and local education agencies (LEA) strongly consider adopting and implementing the NGSS (NSTA, 2016). As of 2020 all but six states have adopted the NGSS or standards based on the Framework for K-12 Science Education. As these states begin or continue implementation of the NGSS, all aspects of the NGSS-aligned science program [curriculum, instructional practice, assessment, teacher preparation, facilities design (Motz, et.al., 2007) and professional learning] must provide deliberate evaluation and communication of science and engineering practices, which must include a focus on student and instructor safety (NSTA, 2015).

Following the release of the NGSS, concerns were raised by science and engineering education experts about the lack of safety mentioned within the NGSS, which were helping guide the development of curriculum and assessment items (NSTA Safety Advisory Board, 2016). These concerns were heard by NSTA and the Association for Science Teacher Education (ASTE) who acknowledged the importance of including safety in pre- and in-service teacher preparation programs. The Standards for Science Teacher Preparation (Morrell et al., 2019) highlight safety as one of the six standards that teacher education programs should address when preparing educators to teach science and/or engineering practices. Safety is also embedded within the learning environments and content pedagogy portion of these standards.

Love, Duffy, et al. (2020) echoed similar concerns in their analysis of various STEM (science, technology, engineering, and mathematics) education related standards documents. They found that many of the documents advocated for hands-on STEM learning, yet safety was not a core component emphasized across the standards. For these reasons, this paper was developed to raise awareness of the need to incorporate safety concepts into instruction and teacher preparation at federal, state, and local levels. Teaching safety concepts is integral to every hands-on STEM learning experience and is a legal obligation shared by both the employer (school district) and the employee (teacher).

Hazard Analysis and Risk Assessment

Throughout this document, references are made to students and teachers performing a hazard analysis and a risk assessment of any scientific investigation and/or engineering design challenge. A hazard analysis is a protocol for workers to focus on job tasks to identify potential sources of harm (hazards) before the tasks are performed. An effective hazard analysis focuses on the relationship between the worker (student), the tasks, the materials used, and the work environment. The Occupational Safety and Health Administration (OSHA) provides many resources to assist teachers and students with developing a standard form template for a hazard analysis of laboratory investigations (OSHA, 2002b).

Risk Assessment takes the results of the hazard analysis to determine the possible dangers to human health, safety, or the environment. A risk assessment will generally focus on 1) the probability of harm, 2) duration of exposure to harm and 3) the severity of harm (National Research Council, 2007). Through the hazard analysis and risk assessment, it can be determined which engineering controls, administrative controls, or personal protective equipment (PPE) may be needed. Alternatively, a hazard analysis and risk assessment may determine that a scientific procedure must not be performed at all (Stroud and Roy, 2015).

Following all hazard analyses and risk assessments, students and teachers need to report the Safety Actions that will be implemented. Teachers should document safety actions in their lesson plans, and also submit a hazard analysis and risk assessment form to their supervisor or administrators prior to conducting any new activities (Roy and Love, 2017). Students should document their safety actions in laboratory reports.) These documented safety actions should incorporate engineering controls, administrative controls, and Personal Protective Equipment (Stroud and Roy, 2015).

Resources for Teachers and Administrators:
NSTA provides an extensive list of resources for safety in elementary schools as well as safety in middle/secondary schools (http://www.nsta.org/safety/). Additionally, NSTA's safety blog provides recommendations for conducting a hazard analysis and risk assessment (https://www.nsta.org/blog/three-step-method-safer-labs). Roy and Love's (2017) book provides an example of a hazard analysis and risk assessment checklist that teachers can submit to administrators prior to conducting new activities.

Safety: A Critical Component of Science and Engineering Practices

The NGSS are unique in that student achievement couples practice with content (NGSS Lead States, 2013, Executive Summary). All of the Performance Expectations of the NGSS begin with a Science and Engineering Practice. Indeed, the three-dimensional representation of the NGSS requires students to use the Science and Engineering Practices to make sense of the Disciplinary Core Ideas of science (National Research Council, 2012). As students apply each Science and/or Engineering Practice to exploring and understanding science phenomena, the following safety provisions should be observed:

Asking questions and defining problems: This practice capitalizes on the finding that children of all ages gain understanding of the natural world by building on prior knowledge of and asking questions about real world phenomena through actively working with the tools of science (Duschl, et al., 2007). This process of defining problems must include a hazard analysis and risk assessment. Hazard analyses and risk assessments are a crucial part of any scientific or engineering protocol. Therefore, students need to be instructed to consider the hazardous implications with any scientific investigation or engineering design challenge.

Developing and Using Models: The NGSS states that models are used in science to represent ideas and explanations. Throughout the learning progressions, students are expected to cite the limitations of various models (NGSS Lead States, 2013, Appendix F). On one hand, models can be used to represent phenomena that are too dangerous to explore directly (for example, ionizing radiation). On the other hand, students should be sure that any model they create include its own hazard analysis and risk assessment, even if that model is a pencil and paper representation of an actual system. If students are designing and constructing prototypes (a fully functioning model), this poses additional safety hazards and risks that must be considered.

Planning and Carrying out Investigations: As students are required to engage in and/or design investigations to make sense of scientific phenomena and/or engineering challenges, schools must ensure that students receive continuing safety instruction prior to investigation design as well as throughout. Furthermore, students must be shown that hazard analysis and risk assessment is a crucial part of planning and carrying out investigations or designing solutions. Safety precautions must be a deliberate and conspicuous component of any investigation or solution. These precautions must also be consistently emphasized across programs and grade levels to help students develop a safety mindset.

Constructing Explanations and/or Designing Solutions: This practice includes having students analyze engineering solutions for feasibility, safety, and compliance with legal requirements (NGSS Lead States, 2013, Appendix F). While NGSS mentions safety in this practice, it is focused on considering the safety criteria of the product designed, not necessarily the process students go through to conduct an investigation, or construct a model or prototype of their idea. It is only in the grades 9-12 practices that the NGSS mentions “Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts. This raises awareness of critical safety precautions that must be considered before, during, and after conducting any investigation or designing a solution. However, the NSTA Safety Advisory Board believes this emphasis on safety should be explicitly included across all grade levels. As students identify various tools, materials, and procedures for designing their solutions, safety training followed by a hazard analysis and risk assessment must precede any work. Safety protocols, including engineering controls and PPE used, should be documented by students.

Engaging in Argument from Evidence/Obtaining, Evaluating, and Communicating Information: Scientists and engineers engage in argumentation when testing a design solution, resolving questions about measurements, or using evidence to evaluate claims (NGSS Appendix F, 2013). Students should be shown that their hazard analysis and risk assessment, and resulting safety considerations and actions are important evidence in supporting their claims of a feasible design solution. In some cases, safety concerns may place cost or time constraints on a proposed solution. Regardless, students must be directed to incorporate these safety concerns as evidence to be used in scientific or engineering arguments.

1. Curriculum and Lesson Development: As SEAs and LEAs implement the NGSS, or standards based on the NGSS, curricular units that are developed must include a thorough hazard analysis and risk assessment. Specific details about these risk assessments may vary according to state and local occupational safety requirements (https://www.osha.gov/SLTC/laboratories/safetyculture.html). However, because curriculum development decisions will reach a wide variety of teachers, students, and families, any curriculum materials or lessons developed using the NGSS should include the following components:

a. General statement of safety precautions relevant to the age and learning readiness of the students. The SEAs or LEAs need to determine the standards of safety to be observed based on 1) developmental age and readiness of students, 2) educational facilities (laboratories, classrooms, and field environments) and 3) local//state/federal laws, regulations, and guidelines.

b. A hazard analysis and risk assessment of the student activities and of the teacher support materials that is a step in the vetting process for adoption of curricular materials. This hazard analysis and risk assessment will evaluate the curriculum or lesson for guidance regarding the following hazards:

   - ***Chemical hazards*** (chemical management guidelines regarding safer storage, use, engineering controls, standard operating procedures, personal protective equipment, and disposal of any chemicals used).

   - ***Physical hazards*** (guidelines regarding safer management and use of electricity, sources of heat, open flame, refrigeration, ventilation, and sound). Physical hazards also include mechanical hazards (guidelines regarding equipment guards/safety shields, safer management and use of sharps, moving parts/projectiles, and moving heavy objects). Trip/fall hazards are also included under physical hazards.

   - ***Biological hazards*** (guidelines regarding safer management and use of live microorganisms, plants, and animals, as well as safer management and use of preserved animals and plants).

- ***Radiation hazards*** These may include ionizing radiation hazards (sources of short-wave ultraviolet waves, radioactive isotopes) or non-ionizing radiation (lasers, bright visible light).

Furthermore, all curriculum materials or lessons should include a list of specific:

- ***Engineering controls*** (e.g., ventilation requirements, eyewash/shower, fire safety equipment, fume hoods, etc.)

- ***Administrative controls*** (e.g. laboratory safety protocols, hazard information of materials, storage and disposal protocols for chemicals, plant/animal care schedules for biology investigations) and

- ***Personal Protective Equipment*** (PPE) (e.g. ANSI/ISEA Z87.1 D3 indirectly vented chemical splash goggles, chemically impervious/fire resistant lab coats, gloves appropriate to the investigation and taking into account any student allergies)

These are needed for all student and teacher activities. Safety equipment must comply with all federal, state, and local requirements. It is the responsibility of the SEA or LEA to provide safety training for teachers responsible for delivering instruction or assessment of NGSS based curriculum. This training should occur upon hiring, or anytime a new hazard is introduced as part of the curriculum (e.g., new chemical ordered, new piece of equipment or tool ordered). This type of teacher training is a necessary part of teachers' professional development to enhance their science pedagogical content knowledge (Duschl, et al., 2007) and is required as part of the LEAs duty or standard of care to protect their employees.

2. Science Safety for All Students: The NGSS presents three-dimensional science and engineering standards for all students at all grade levels. Students with a variety of learning differences and educational settings are expected to meet the new standards (NGSS Lead States, 2013, Appendix D). Each student group presents a unique set of challenges and opportunities to science educators. For this reason, safety instruction and hazard analysis/risk assessment should be incorporated into all science instruction and assessment delivered to every group. Appendix D (All Standards All Students) of the NGSS (NGSS Lead States, 2013) expresses the role of informal educators, of community resources, and of parents in the delivery of science education. Each of these groups require professional development in science safety protocols as well as hazard analysis and risk assessment.

In addition, Appendix D recommends use of Universal Design for Learning (http://www.udlcenter.org/) as a starting point for providing accommodations or modifications to students with various learning differences. Universal Design for Learning may also be a starting point for assessing and providing for safer procedures and provisions for these students. An important part of the hazard analysis and risk assessment of curricula and lessons will include meeting the needs of students with disabilities or students with limited language proficiency. Any instruction related to safer practice or safety equipment must be accessible by all students and teachers with physical or learning differences.

> ***Resources for Teachers and Administrators:***
> NSTA provides an extensive list of resources for safely modifying or accommodating instruction for students with various types of disabilities (https://www.nsta.org/disabilities/). Additionally, Love, Roy, et al. (2020) highlight a number of open access safety resources to assist students with disabilities in STEM (science, technology, engineering and mathematics) labs and makerspaces.

3. Engineering and Tools: The NGSS raises engineering design to the same level as scientific inquiry at all levels of PK-12 science education (NGSS Lead States, 2013, Appendix I). The core idea of engineering design incorporates three components: Defining and delimiting engineering problems, designing solutions to engineering problems, and optimizing the design solution. In many cases constructing models or functioning prototypes and engaging in the engineering design process will involve the use of hand tools, power tools, and fabrication equipment more common to technology and engineering education labs rather than science laboratories. Teachers have a responsibility to conduct all activities they assign in the safest possible manner, regardless of where it occurs.

Many of the engineering and STEM or STEAM (science, technology, engineering, the arts, and mathematics) activities that students and teachers engage in may involve the use of hazardous tools (hand and power) and equipment. Before using these items with students, teachers need to demonstrate their understanding of the safer use of each item and the personal protective equipment that must be used with each. Teachers should provide evidence that they are familiar with the safe operating and maintenance procedures of each item which can be achieved through assessments and proper training offered by the SEAs, LEAs, teacher preparation programs, or other qualified training sources.

Specifically, science/STEM teachers who have not learned to use engineering tools and equipment as part of their professional preparation may need additional training. Employers are required to provide this training according to OSHA (OSHA, 2002a), when they are assigning teachers to teach in areas outside their professional expertise. Providing this training will help teachers to reduce and avoid potential liability and accidents in laboratories and makerspaces. Collaboration with technology and engineering educators may help science teachers explore better professional practices with regard to tool and equipment use as well as teaching engineering design (Love, 2018).

Resources for Teachers and Administrators:
OSHA provides guidelines on Hand and Power Tool safety which should be consulted before any tool is used in a laboratory or makerspace (https://www.osha.gov/SLTC/handpowertools/). The International Technology and Engineering Educators Association (ITEEA) also provides an extensive list of resources and assessments for safer tool and equipment use to teach engineering practices (https://www.iteea.org/Resources1507/Safety.aspx)

Engineering Tool and Equipment Safety Recommendations
Districts should have standard operating procedures for the use of tools (hand and power) and equipment. These procedures should be developed in collaboration with technology and engineering educators and should include engineering controls, personal protective equipment, safety protocols, and procedures for using hazardous materials and equipment (Love, 2018; Roy, 2014, 2015). To further enhance safety, districts can use posters and other classroom resources such as those highlighted by ITEEA to promote the safer use of tools and equipment.

There are five basic rules that should be followed to prevent the hazards associated with hand and power tools (OSHA, 2002a):

- Keep all tools in good condition with regular maintenance.
- Use the right tool for the job.
- Examine each tool for damage before use and do not use damaged tools.
- Operate tools according to the manufacturer's instructions.
- Provide and use properly the right personal protective equipment.

Before having students use tools (hand and power) and pieces of equipment, safety rules should be reviewed and documented in the lesson plan. Teachers should also have students and parents sign a safety agreement that specifically makes them aware of any tool, machine, and chemical hazards that students may encounter during the academic year. An example of such an agreement is below.

Safety Acknowledgement Agreement for the Use of Tools and Equipment

Before working in any laboratory or makerspace where tools (hand and power) and equipment are being used, students must review the rules below and agree to abide by these rules. Parents and guardians are asked to review these rules and emphasize to the student the importance of behaving in an appropriate manner in any area where tools and equipment are in use. Students and parents/guardians are asked to sign this document acknowledging they reviewed and agree to follow the rules, and then return it to their teacher.

1. Always understand and follow directions when using any hand or power tool. Pay attention to the nameplate on the tool and any warnings that may be listed on the tool itself.

2. Always wear the appropriate protective equipment, including safety goggles or safety glasses with side shields. Dust masks should be worn with tools that will produce dust, and hearing protection should be worn if a tool is to be used for a prolonged period of time.
3. No loose-fitting clothing, neckties, jewelry or dangling objects of any kind should be worn.
4. Tie long hair back and out of the way.
5. Closed toed shoes, preferably with non-slip soles should be worn. Sandals and flip flops are not to be worn when hand and power tools are in use.
6. Hand and power tools should not be used if you are tired, distracted, ill or under the influence of drugs or alcohol. Even over the counter drugs, such as cold medicine can negatively affect your ability to concentrate when you are using hand and power tools.
7. Work areas should be clean before and after you work with tools to prevent debris being ignited by hot tools or sparks.
8. Work zones for power tools should be well defined with yellow and black stripped floor markings and have plenty of light. Only one tool operator is allowed in the work zone when in operation.
9. Switches should be OFF before any power tool is plugged in.
10. All guards should be in place and working before a tool is used.
11. Tools should be turned off and unplugged before adjustments are made.
12. Only accessories designed for a particular tool should be used.
13. Power tools should not be used in wet or damp conditions.
14. If a tool is damaged or not functioning properly it should be reported to the teacher and not used.
15. Only heavy-duty extension cords should be used and kept out of walking areas to avoid creating trip/fall hazards.
16. Only cutters and blades that are clean, sharp and securely in place should be used.
17. Students must behave appropriately in the laboratory or makerspace. At the teacher's discretion, any student failing to behave in an appropriate manner will be removed from the learning setting and the school's progressive disciplinary policies will be followed.
18. Take your time when you work, and pay close attention to what you are doing.
19. Always use the right tool for the job.
20. Unplug, clean, and store any tool that you have used in its proper place at the end of the period.

I ______________________________________ have read the rules of Safer Tool and Equipment use and agree to abide by each and every rule.

____ _______________________
Student's Signature Date

I have reviewed the above set of rules with my child and will encourage them to abide by each rule so that they can operate safely in the laboratory.

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Parent/Guardian's Name

Parent/Guardian's Signature Date

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