Report of the

Postsecondary and Workforce Science Readiness Working Group

Minnesota P-16 Education Partnership

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Introduction

In March 2008, the Minnesota P-16 Education Partnership formed a Postsecondary and Workforce Science Readiness Working Group to examine and define postsecondary and workforce science readiness in Minnesota. Membership consisted of representatives from university and college science faculty, high school science faculty and businesses. The specific charge to the group was to:

> "……develop broad recommendations for strengthening and enhancing Minnesota's K-12 academic standards in science. The working group should seek to promote alignment between Minnesota's science standards and: (a) the science readiness expectations of postsecondary institutions in Minnesota and around the country, and (b) recognized national and international science education frameworks."

In response to this charge the working group examined overall standards issues and those involving the four major science strands included in international, national and state standards. The requirements expected for entry into the workforce of today and the future match well with the expectations for post secondary success. The Science Reading Working Group adopted the following definition from *Ready or Not: Creating a High School Diploma That Counts* for its review and recommendations:

> College and work readiness: The knowledge and skills that all high school graduates need to do credit bearing coursework at state colleges universities and or to embark successfully on career-track positions in high growth, highly skilled "good jobs." (A good job is defined as one that pays enough to support a family well above the poverty level, provides benefits, and offers clear pathways for advancement through further education and training.)

Members met both as a whole and as subgroups to examine existing documentation, discuss various perspectives, and offer insights from their extensive experience. The subgroups were formed to match the four strands of the current Minnesota science standards: life science, physical science, earth and space science, and nature and history of science.

From the beginning the Science Readiness Working Group noted that while standards are important, they are not sufficient to develop scientifically literate graduates. The impact of standards depends upon implementation that includes teacher quality, instructional strategies, resources and support. To fulfill its charge of "developing broad recommendations for strengthening and enhancing Minnesota's K-12 academic standards in science," the group found it important to comment on those areas of the education system that influence standards-based instruction. While this was an independent decision, it is one supported by the National Research Council's 2006 publication, *Taking Science to School: Learning and Teaching Science in Grades K-8.*

This Science Readiness report starts with broad recommendations to improve the Minnesota science standards. This is followed by reviews of international, national and state standards, national reports on K-12 and post-secondary expectations and the administrative and instructional experience of members. The information from the reviews as well as the experience of the Science Readiness Working Group are the underpinnings of the recommendations. The group also realized that improving Minnesota's science standards impacts other parts of the educational system. The implications of the proposed science standards improvements are addressed in the final section of this report.

Recommendations

Suggested changes to the K-12 Minnesota academic science standards are based on the fundamental premise that the standards must apply to all students and that all students have access to high quality science instruction. This is consistent with national and international standards. It is important that no student is precluded by the state's standards from entering post secondary education ready to pursue a science or technology based career, even if the student was not inclined to do so in high school.

Minnesota student scores rank near the top of national science tests such as the National Assessment of Educational Progress. However, the average score obscures the fact that a significant number of students are not completing high school with the requisite scientific and mathematical understandings for success in the workforce or entry level college courses. Standards for all students accompanied by differentiated instruction are critical to closing the existing achievement and opportunity gap between the performance of Minnesota students from differing racial, ethnic and income groups

The following recommendations are important for general workplace readiness, post secondary success and civic responsibility. The list is deliberately short in order to draw attention to the most important issues, those that can lead to significant improvement in the standards, increased science literacy for students and a strong Minnesota workforce.

Recommendations for Minnesota Science Standards

- Reduce the number of standards to develop a deep understanding of the essential and relatively few "big ideas" of science.

- Structure benchmarks that are specific enough to provide adequate guidance for state-wide assessment, yet flexible enough to allow teachers to design instruction in a variety of appropriate contexts. This would enable teachers to design instruction to take advantage of their expertise, the local environment and the interests and needs of their student.

- Change the current topic focus of the standards to one that concentrates on concepts to provide greater depth of understanding, which prepares students for further learning.

- Emphasize critical thinking, problem solving, quantitative reasoning, observation and design.

- Address connections between and among science disciplines and between science and technology, engineering and mathematics.

- Use the process of scientific inquiry along with facts, models and theories to instill an understanding of the natural and the designed world.

- Emphasize the relevance of science to students' personal experience including how to creatively apply scientific principles to technological design.

- Design standards in such a way that they are relevant, implementable and assessable.

- Revise the 2004 bench mark on scientific and technological innovations to better reflect the process of science by inserting "support and refine" so that the benchmark reads:

  > The student will be able to explain, how scientific and technological innovations as well as new evidence can *support, refine and* challenge portions or entire accepted theories and models including but not limited to cell theory, atomic theory, theory of evolution, plate tectonic theory, germ theory of disease and big bang theory.

Recommendations in Support of Minnesota Science Standards

- Support the teaching of science standards through high-quality professional development for teachers and administrators that includes the standards for professional development outlined in the *National Science Education Standards.*

- Develop a curriculum frameworks document to support the implementation of the science standards.

- Structure the substance and reporting of the state science assessments in such a way that they provide timely and useful information that can guide instructional improvement.

- Urge Minnesota postsecondary institutions and the business community to develop an explicit set of science criteria/competencies for students entering their institutions.

Rational in Support of the Recommendations

The suggestions to improve the Minnesota science standards are based upon a review of the international, national and state science standards as well as key reports that have received national attention. In looking at national standards, the Science Readiness Working Group focused on two major documents, the standards developed by the National Research Council, the operating arm of the National Academy of Science, and those developed by the American Association for the Advancement of Science's Project 2061. The standards in these documents are intended for all students. However, it must also be recognized that these pioneering documents are, to some extent, outdated in light of a decade of experience in developing and assessing science standards. The National Research Council emphasizes this in its 2006 publication, *Taking Science to School: Learning and Teaching Science in Grades K-8.*

Science for All

Minnesota state standards should be rigorous enough to prepare all students for entry level postsecondary education science and technology courses. The future of our students should not depend on being tracked into or out of specific science courses. An understanding of science is necessary for an increasing number of non-scientific careers and jobs, and is increasingly important for responsible citizenship. Citizens are routinely being asked to evaluate scientific information and projections in order to make decisions about food supply, disease, climate change, energy availability, transportation and communication. Scientific information plays a role in shaping policy decisions; the most rapid job-growth sectors require science and/or technologies based on science. It is no longer possible to leave science to "experts" and still be a responsible contributing member of society. To prepare all students for this responsibility, the science standards must emphasize core scientific concepts, the "big ideas" of science. They must also include the distinguishing characteristics of science such as critical observation, controlled experimentation, careful measurement, appropriate modeling, connection to theory, fair and ethical communication and working with peers to develop ideas. Finally, the science standards must begin to break down the boundaries between scientific disciplines and focus on the interconnections between and among the disciplines. To understand and resolve challenges such as climate change or energy availability requires knowledge of physics, chemistry, life science and earth science.

Relationship to Teaching Standards

In contrast to the Minnesota science standards, national standards and a number of state standards include expectations for appropriate instructional strategies. These include an overarching framework, commentary, and preamble or preface that help school districts and teachers implement appropriate curriculum with strategies that promote a focus on the big ideas of science and the integration of those concepts with real world situations. Massachusetts offers a good example of this practice. The Science Readiness Working Group understands that teaching standards are dealt with separately in Minnesota. However, this type of supporting documentation should be available. For the future, the rationale for the separation of content and teaching standards should be carefully examined and changes considered.

Extent of Alignment with National Standards

In general, the current Minnesota standards align with the content of the original national standards. However, the detailed benchmarks which appear to drive curricular and testing decisions focus on the lower end of thinking skills. Minnesota standards are weak in addressing the skills expected of students who enter college and are sought after in the workplace. The current standards rely too much on "know" and "understand" as outcomes. This can be addressed by connecting each standard to a "big idea" and presenting the benchmarks as important concepts instead of topics. The expected outcomes should focus on the direct engagement with the processes of science. This view is consistent with the National Research Council's recent reviews of the national standards.

Along with the concern that the Minnesota science benchmarks contain too many topics, some of which are only loosely connected to the standards, the Science Readiness Working Group questioned the appropriateness of having standards for each grade, rather than following the national standards and most other states by placing the standards in grade bands. Since the required testing takes place at grade intervals, rather than at each grade, it makes sense to allow for flexibility in concept development by individual school districts.

Findings from Cognitive Psychology

Since the national standards were published in the mid 90's research in cognitive psychology has provided a better understanding of what children know and how they learn. Any revision of the Minnesota standards should reflect that understanding. This concern of the Science Readiness Working Group is stated well in the National Research Council publication, *Taking Science to School: Learning and Teaching Science in Grades K-8* in 2006 and the follow-up 2007 publication *Ready, Set, Science!: Putting Research to Work in K-8 Classrooms.* The latter has an up-to-date analysis of the National Research Council science standards in light of their application and recent research about learning.

In addition to what children are capable of learning, attention must be paid to motivation. This is best achieved by building upon natural curiosity that includes interest, fun and relevancy. Young children can be engaged by simple "why" questions that spark their natural curiosity. Older students are easily motivated when engaged in the science and engineering through "everyday items" such as iPods, cell phones, television, and computers. "Adults play a central role in promoting children's curiosity and persistence by directing their attention, structuring their experiences, supporting their learning attempts, and regulating the complexity and difficulty of levels of information for them."[1]

Science and Math

Quantitative reasoning is integral to science. Mathematics and its relationship to science should be built into the science standards from the early grades. The Minnesota science standards need greater emphasis on quantitative reasoning and solving of realistic complex problems that require multi-step reasoning. Recent research by Sadler and others indicates that a solid mathematical background is the best indicator of success in introductory post secondary science classes.

Science and Technology

Science, Technology and Engineering are closely related. The Minnesota Science Standards need to demonstrate this relationship. According to The National Science Education Standards an understanding of technology is necessary for an accurate understanding of science. The document states the relationship as follows:

> As used in the Standards, the central distinguishing characteristic between science and technology is a difference in goal: The goal of science is to understand the natural world, and the goal of technology is to make modifications in the world to meet human needs.

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[1] Taking Science to School: Learning and Teaching Science in Grades K-8. p. 5.

Scientists and Engineers frequently work together. But for student awareness and career opportunities it is important that they learn the distinction between the occupations of scientists and engineers. The 2006 New Hampshire K-12 Science Literacy Curriculum Framework states the distinction as “Scientists propose explanations for questions about the natural world, and engineers propose solutions relating to human problems, needs and aspirations.”

Theory in Science

Science uses theory in a precise way. Since an understanding of a “scientific theory” is central to science, it is important that students understand what a theory is, that it is not simply a notion, a hunch, or speculation. A scientific theory is a complex web of consistent models held together with many different types of measurement and observation. It is supported with an abundance of evidence that makes it unlikely to be abandoned. A theory may be modified but only when there is compelling new evidence to do so. “The business of science is to build theories that explain how the natural world works and predict how it might work in the future.”[2]

Specific Discipline Concerns

In addition, to these overall concerns, there were a number of particular concerns regarding the various science disciplines that are given in Appendices two to five. A summary of those concerns follows.

Physical Science Concerns

The physical sciences subgroup noted that the Minnesota standards need to place more emphasis on the big ideas of chemistry and physics. The Minnesota standards attempt to arrange the physical sciences standards according to “big ideas” but they get lost at the benchmark level. An example of a statement of these big ideas has been articulated in the Advanced Placement redesign process. Although Advanced Placement deals with a higher level of understanding than would be required of all Minnesota students, the big ideas are suitable for all. The big ideas from the preliminary work in physics are:[3]

- Objects and systems have properties such as mass, charge and internal structure
- Fields existing in space can be used to explain interactions
- The interaction of an object with other objects is described by forces which can cause a change of motion
- Interactions between systems can result in changes in those systems
- The interaction of one object or system with another is governed by conservation laws
- Some phenomena can be described as waves
- The evolution of a complex system over time is described by probability

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[2] 2006 New Hampshire K-12 Science Literacy Curriculum Framework, p. 10.

[3] Cain, Laurence, "AP Redesign Update: Motivations, Methods, and Results for the Design of New Courses and Exams.” Presentation Association of Physics Teachers (AAPT) meeting, Edmonton, Canada July 22, 2008

At the present time, the AP redesign for chemistry has not been made public. Major topics suggested by a number of chemists include:

- Conservation of matter and energy
- Particulate nature and states of matter
- Atomic structure
- Patterning of information arranged in the Periodic table
- Interactions between atoms; bonding theories and chemical reactions

Life Science Concerns

The life sciences subgroup also expressed concerns over the number of life science benchmarks. Currently details take precedence over important concepts. The benchmarks need more relevancy to allow students to connect to current issues that they can address directly with local research that contribute to state or national databases.

The big ideas or concepts of the life sciences that students should be expected to understand upon graduation are:

- Evolution explains both the unity and diversity of life.
- Living things are composed of cells that form the basic structure and perform the basic functions of life.
- Living things display varying and profound degrees of interdependence from the cellular to the ecosystem levels.
- Life, from individual cells to ecosystems, requires a constant input of energy to remain organized.
- Organisms grow, reproduce and develop in predictable ways governed by information encoded in sequences of DNA known as genes.

Earth and Space Science Concerns

The Earth and Space Science subgroup expressed concern for inappropriate age-placement of standards. In particular, the AAAS Atlas of Science Literacy indicates that students are not ready to tackle complex topics such as plate tectonics until approximately grade 8. Yet, the Minnesota standards introduce the concept as early as the 4th grade. More important, in spite of the inclusion of grade 9-12 Earth and Space standards, most Minnesota students last study Earth Science in the 8th grade. This results not only in a mismatch between content and age appropriateness, but means many students do not study the significant concepts of earth and science. Given the 21st century focus on energy and environmental issues, The Earth and Space Science subgroup recommends greater focus on an integrated "earth systems" approach. The subgroup also emphasized a need to reduce the focus on learning discrete facts and to increase the emphasis on standards that require students to make observations and collect data about the world around them.

Earth Science by Design, developed by the American Geological Institute and TERC, lists 25 concepts or “big ideas” that scientists and educators have identified as the major earth and space science ideas for middle and high school students. While the entire list is provided in the appendix to the Earth and Space science subgroup report, the following big ideas distilled from that report are:

- Earth can be conceived as an interacting set of processes and structures composed of the atmosphere, geosphere, hydrosphere and biosphere.
- Radiation, conduction and convection transfer energy through Earth’s systems.
- Circulation patterns in the ocean are driven by density differences and by exchange of momentum with the atmosphere.
- The movement of Earth’s lithospheric plates causes both slow changes in the earth’s surface (e.g. formation of mountains and ocean basins) and rapid ones (e.g. volcanic eruptions and earthquakes).
- Liquid water in great abundance makes Earth unique among the planets of the solar system.
- Human beings have a unique, large and growing impact on Earth systems.
- Energy conversions underlie all Earth processes.
- Humans depend on ecosystem services.

Nature and History of Science Concerns

The nature and history of science subgroup noted that the “scientific inquiry” sub-strands do not include consideration of the way in which scientists learn from repeated trials, from refining what does not work into what does work. In science, lack of success is not the same as failure. Students need to understand that evaluating observations and experiments is a necessary part of science. It is the way to learn from unexpected results. The subgroup also noted the importance of integrate engineering standards into the science standards. However, it will not be possible or desirable to embed all the engineering standards into the current science standards. Those engineering standards that do not fit within the science standards can be included under the category “scientific enterprise.”

Postsecondary Science College Readiness

Minnesota Colleges and Universities vary in the documentation provided regarding science expectations for introductory courses. In 1993 MnSCU published a document listing the competencies necessary for success in a Minnesota State University. Most of the requirements are process skills, but they also include content competencies, such as fundamentals of cell biology or the structure of an atom, expected for the life, physical and earth sciences. No recent documents were located for individual state universities or for the two year colleges. Some, but not all, MnSCU campuses offer introductory level science courses where the content can be viewed as fulfilling expectations for college science readiness. The Science Readiness Working Group could not find any University of Minnesota expectations for college science readiness but noted that the university’s general outcomes expected for its graduates could be back-mapped to readiness criteria.

A number of national organizations including the American Association of Universities, The College Board and ACT have issued statements on postsecondary expectations that include specific reference to science. The consistent emphasis is on the process of science as skills students will need upon entering the science classroom. The higher education members of Science Readiness Working Group share this view based on the comments of science colleagues and their personal experience.

One of the most important skills is quantitative problem solving which requires mathematical skills. Recent work by Sadler and others shows that mathematics and quantitative problem solving is a major factor leading to success in college science courses. According to the research the best preparation comes from high school courses that (1) use lots of math (2) concentrate on key concepts, rather than coverage, and (3) use labs judiciously to change misconceptions. The work goes on to say that high school courses need to provide students with specific writing and problem solving skills such as (1) analyzing pictures or illustrations, (2) drawing graphs by hand and interpreting them, (3) solving quantitative problems, (4) focusing on labs that address student beliefs, (5) testing for facts and (6) mastering selected foundational concepts.

From its study the Science Readiness Working Group concluded that the current Minnesota Science Standards are currently deficient in preparing students for post secondary study. They place heavy emphasis on specific facts, rather than overarching concepts. There was unanimous concern that standards should emphasize the essential processes that distinguish scientific inquiry from other ways of knowing.

Implications of Suggested Standards Changes

As the Working Group examined the changes necessary to ensure the science readiness of Minnesota high school graduates, it became apparent, that implementation of the science standards also had to be considered. The preparation and professional development of teachers, the availability of resources and appropriate assessments are crucial to standards implementation. Of particular importance is the value administrators, teachers, students and parents place on the importance of standards-based instruction. An analysis of the PISA (Programme for International Student Assessment) results shows that where there is broad agreement among the overall community for teaching the standards, students learn the standards. Student achievement, regardless of poverty, students' native language or the specificity of the standards, was the highest in those countries where administrators, teachers, parents and students all recognized the importance of standards and focused on them.

Teacher Preparation and Professional Development

The Science Readiness Working Group found teacher quality of such importance that it chose to draw attention to the major issues affecting the recruitment and retention of a quality science teaching force in Minnesota. The recommendation that Minnesota science standards and benchmarks stress the big ideas of science is a change from the current standards. This change will require curriculum adjustments and make appropriate professional development crucial.

Pre-service programs that prepare the beginning teacher will need to be re-examined. College and university courses should include the importance of working with standards in designing appropriate instruction. Colleges and university courses also need to target science content that is relevant and important for future elementary teachers.

Once teachers enter the classroom, the transition from novice teacher to expert teacher requires sustained in-service professional development that is both content and pedagogy specific. Like the medical and legal professions, teaching requires regular continuing education. The expectation of continued participation in sustained professional development can be instilled as part of pre-service preparation, but the state and school districts must commit to providing high-quality, focused science professional development for teachers at all levels of the K-12 spectrum.

Evidence has shown that short term workshops, no matter how intensive, are not sufficient to prepare teachers to work with new curricula or strategies. Teacher support must be sustained over time. *Lessons from a Decade of Mathematics and Science Reform”* provided extensive data to support this view. Results showed significant student achievement gains only as teachers approached 30 hours of professional development with continuing student achievement gains as teachers reached 80 hours of professional development. Continued professional development is important for all science teachers but it is particularly important for grades K-6 where many teachers have limited education in science. While it is the early grades where teachers express the least confidence in scientific understanding, these are the grade in which students form their attitudes toward learning science which, in turn, influences career interests.

Teacher Licensure

Minnesota has long taken pride in the quality of its teachers as measured by the overall achievement of the state’s students. However, new requirements for teaching in the various science disciplines has led Minnesota to consider alternative paths to licensure. Many small schools do not have enough students to employ a full time physics, chemistry and earth science teacher. This is an issue that state licensure requirements must face.

This spring the state board of teaching voted to allow teachers to meet licensure requirements by a single measure; passing the Praxis II discipline science exam. However, the exam covers only 40% of the science content required by the state licensure standards. It does not demonstrate the competency necessary to teach Minnesota’s secondary science courses. Equally important, the exam does not align with the current science standards, and is unlikely to align with revised standards.

The Science Readiness Working Group urges the Minnesota P-16 Education Partnership to study this issue in more depth and in concert with MnSCU, the University of Minnesota and other teacher training providers develop alternative licensure programs that meet the needs of small school districts and put in place a professional development program to help teachers without sufficient licensure attain the necessary competence. Options such as on-line learning, a portfolio process developed by the MN Board of Teaching as well as several alternative licensure programs being developed at several MnSCU institutions and Minnesota private colleges hold promise.

An example of a more specific licensure problem stated earlier, is the disconnect between the Earth Science licensure and the placement of Earth and Space science standards. Most of the standards are placed in the 8th grade, while licensure is for grades 9-12. The current licensure structure means that many 8th grade Earth Science classes are taught by teachers holding elementary licenses with a middle school specialty. They are unlikely to have the necessary requisite knowledge of earth science.

Investments and Resources

Embedded in the Science Readiness recommendations listed earlier is the understanding the students will be actively engaged in "doing" science. This means that classroom size must be manageable, both for the teacher to monitor and assist all students in their explorations and for classroom safety. It is simply not possible in most classroom settings to have 40 students safely engaged in some form of scientific experimentation. Rigorous science can be done with low-cost materials and equipment, particularly at the elementary level. However the consumable materials and scientific equipment must be regularly replenished and maintained. It is essential to commit long-term funding to these minimal resources for science. Not only is this essential for student engagement in science, it sends a message to teachers regarding the value the community places on science.

With the current emphasis in elementary schools on reading and math, science is frequently not taught at all or on an irregular basis. Often is only available for students who have mastered their reading and math assignments. Yet, it is in the early elementary years that students frequently form long-held opinions of science. Science needs to be treated as a core subject, and as such, schools need to provide students with direct, active engagement with science on a regular basis.

Student Improvement Data

Successful attainment of the science standards is necessary for all students to become scientifically literate by graduation. It is important for administrators and teachers to know the extent to which students are progressing and to adjust instruction or intervene where students are having difficulty. This means that Minnesota state assessments intended to measure student performance relative to the state's science standards must be done in such a way that they provide useful information for teachers and schools to improve their instruction in a timely manner. School districts and teachers currently have difficulty with both the current timing of assessment reports and the specific information provided by the tests.

Conclusion

Minnesota has been known for its fine educational system. While it is not yet in the crisis mode that exists in several other states, funding and support for public education has declined in recent years. Educational excellence is a key element of economic survival and success. To continue to have an excellent educational system, Minnesota must build on its success. With this in mind, the Science Readiness Working Group focused on what would improve the Minnesota science standards. As the report stated, the topics in the current standards do align with the original national standards, but not with current national thinking or recommendations. Since the national standards were published, much has been learned from cognitive psychology, national and international assessments and from the experience of implementing the standards that makes the short comings of the current Minnesota science standards evident. This is an opportune time to improve them.

Members of the Science Readiness Working Group thank the Minnesota P-16 Education Partnership for the opportunity to examine and reflect on the Minnesota’s current science standards and the many implications surrounding them. Discussions were invigorating, friendships were formed or renewed, and all return to their work with increased appreciation for the work of Minnesota’s science teachers.

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Physical Science Subgroup Report

The concept of readiness as an outcome of the MN standards requires looking into the future. In the fast moving world we live in, educational standards must prepare students for a world at least a decade in the future. One method of looking at this task is to recognize that the minimum required level of education necessary to make a decent living to support a family continually increases. In the time of current students' great grandparents, a primary school education was sufficient to reach that level. Their grandparents needed some high school education, their parents needed to graduate from high school. Today's students will need some higher education to reach the same economic level. Within a decade that level will require a college or technical degree. For this reason, we have considered the minimal MN standards to be those that would lead to at least minimal success in current introductory classes as institutions of higher education in our state. This also insures that no student will be deprived of the opportunity of obtaining a higher education degree because they did not consider it a goal while in public school.

Unfortunately we could find no written documents from any institution of higher education in Minnesota that specified the minimal competencies needed to succeed at that institution. Perhaps an offshoot of this effort would be to encourage such a document from U of M and MNSCU. In lieu of this documentation, we used the U of M Learning Outcomes for their graduates as a guide and to determine the prerequisites that might be necessary from grades 1-12. We also used the recent research from Sadler et al that determines what aspects of the high school curriculum contributes to success in introductory college chemistry and physics classes. Many more general documents were used such as the National Academy Publications: Rising Above the Gathering Storm, Taking Science to School: Learning and Teaching Science in Grades K-8, Ready, Set, Science, National Science Education Standards (NCES) and the AAAS Project 2061 and Benchmarks, and the physical sciences standards of other states and countries.

The U of M Outcomes are:

1. Can identify, define, and solve problems
2. Can locate and critically evaluate information
3. Have mastered a body of knowledge and a mode of inquiry
4. Understand diverse philosophies and cultures within and across societies
5. Can communicate effectively
6. Understand the role of creativity, innovation, discovery, and expression across disciplines
7. Have acquired skills for effective citizenship and life-long learning.

One can make a case that they all apply to learning in the physical sciences. Indeed, 1,2,5, and 6 are intimately part of the fundamental understanding of science, the so called "scientific method." The prerequisites of these outcomes must be addressed directly in any state standards for the physical sciences and should be a continuous theme within all sciences. The prerequisites to outcome 3 are the goal of any set of state standards and encompasses the essential content, context, and processes of physical sciences. An example of a rough analysis of the prerequisites for outcome one, problem solving, and possible grade levels in which they can be addressed is attached. It should be noted that problem solving, which in engineering is called design, is a major educational goal in every report on educational needs. The process of problem solving can be summarized as making a series of decisions that goes from a situation to a desired outcome when the path between them is not known. This process usually involves the following components:

- Clarify the situation and the goal.
- Identify what external knowledge is necessary from a science discipline.
- Plan a solution path.
- Execute that plan.
- Evaluate the answer and revise the solution if necessary.

Most of the decisions inherent in problem solving involve qualitative analysis but the role of mathematics is an essential tool and language of physical sciences. The need for this mathematical content in physical sciences must be made apparent in standards.

The Sadler papers on Chemistry and Physics are really the first large scale research on the factors from high school that determine success in introductory college courses. Since it is the first such study, one could expect some of these findings to change with more refined follow-up studies. For example the Physics Education Group at U of M is now conducting such analysis on success factors for introductory physics at U of M. Nevertheless it is the best data there is and should be respected in the state standards. One clear message is that more mathematics and practice with quantitative problem solving is one of the largest factors in determining success. Note that quantitative problem solving should not be interpreted as plugging numbers into formulas. From one of Sadler's presentation, he claims the following items are important to achieve success at the college level:

"Students need writing and problem solving skills from high school.
What Helps:

- Analyze Pictures or Illustrations
- Draw/Interpret Graphs by Hand
- Quantitative problems
- Labs Addressed Student's Beliefs
- Testing for facts
- Mastery of select foundational concepts

The best preparation comes from high school courses that:

- Use lots of math
- Concentrate on key concepts, not coverage
- Use labs judiciously to change misconceptions"

Because the MN standards for physical science do not address the processes that define the essence of science, they do a poor job in reflecting the science readiness expectations of postsecondary institutions. Many important chemistry ideas seem to be missing entirely. One should note that science is not a collection of facts or even an organized catalog of facts. It is the procedures of science such as: problem solving, evaluating data, model building, and the criteria for testing models, to name a few, that distinguishes it from other fields. Paraphrasing a famous physicist from the early 20th century, science is not the same as bird watching.   Facts are important but they cannot be detached from the scientific processes and remain meaningful. Likewise scientific processes cannot be detached from the facts and theoretical constructs that give them meaning.

Although there is an attempt to arrange the MN physical science standards in terms of the big ideas (at least in physics), this organization seems to be lost at the benchmark level. An example of the big ideas in physical sciences appropriate for high school graduates was articulated in the status report of the AP Redesign Project of the College Board. Their Physics Commission articulated the following as the big ideas in physics:

- Objects and systems have properties such as mass, charge, and internal structure.
- Fields existing in space can be used to explain interactions.
- The interaction of an object with other objects is described by forces which can cause a change of motion.
- Interactions between systems can result in changes in those systems.
- The interaction of one object or system with another is governed by conservation laws.
- Some phenomena can be described as waves.
- The evolution of a complex system over time is described by probability.

A similar list of big ideas from the AP Chemistry Redesign Commission was:

- Matter is made from discrete, fundamental units called atoms.
- Chemical and physical properties of materials can be explained by the structure and the arrangement of atoms, ions or molecules and the forces between them.
- Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
- Rates of chemical reactions are determined by details of the molecular collisions. The laws of thermodynamics explain and predict the direction of changes in matter.
- Equilibrium is a dynamic, reversible state in which rates of opposing processes are equal. Competition between reactants and products in the presence of external perturbations of all systems.

Although the AP redesign project seeks to define a high school course suitable for college credit, their articulation of big ideas is applicable at any educational level. As such they are suitable to serve as examples for K-12 physical science education. They are also consistent with a distillation of the National Standards and other state standards. Note that in this same document, they also identify other elements that are the essential processes of science for which they also intend to assess.

The MN benchmarks seem to be constructed to include topics that are thought to be important whether or not they are essential to the big idea of the standard or sub-standard. The result is a set of learning requirements that is incoherent and idiosyncratic. A consistent way of choosing topics to be included in the benchmarks is to eliminate those that are not directly relevant to the standards and sub-standards. Difficult choices must be made to avoid the trap of having a curriculum that is a mile wide and an inch deep, the hallmark curricula that result in poor student performance.

The standards need a clearly stated rationale and framework. One good model of this is the Massachusetts standards. Also in order to illustrate what is meant by the standards, Massachusetts includes examples of classroom lessons. Such concrete examples are important to allow teachers to understand what is required. A sterile list of topics can be subject to much misinterpretation.

It is important to realize that the National Standards and many state standards were written over a decade ago. Since that time much has been learned about the process of setting standards. We find particularly apropos the following recommendations from Ready, Set, Science!: Putting Research to Work in K-8 Science Classrooms published by the National Research Council in 2007. This has an up-to-date analysis of National Academy Science Standards (NSES) in light of their application and modern knowledge about learning. Its message is that states should not blindly apply the NSES standards because more has been learned since they were established. Below is a relevant passage from its recommendations:

> “The development of standards and benchmarks was an important step toward building and expressing shared values for K-12 science education. These standards succeeded in building common frameworks. While standards were marginally rooted in research on children’s learning and analyses of scientific practice, we now have a richer research base to inform science education and a better sense of the critical role this research should play.
>
> Current national, state, and district standards do not provide an adequate basis for designing effective curriculum sequences, for several reasons. First, they contain too many topics. When the *NSES* were compared with curricula in countries that participated in the Third International Mathematics and Science Study, the *NSES* were found to call for much broader coverage of topics than those in high-achieving countries.
>
> Second, the *NSES* and benchmarks do not identify the most important topics in science learning. Comparisons of the *NSES* with curricula in other countries show that they provide comparatively little guidance for sequencing across grades. As we pursue a course of organizing curricula around core ideas, we need to ask ourselves questions that were not central to the development of the current standards. What areas of study are critical for students’ future learning? Which of these critical areas of scientific study can students explore in meaningful and increasingly complex ways across the K-8 grade span and beyond? Which areas of science can safely be deferred until high school or college? These are not easy questions, and answering them will require collective, sustained attention and focus among a number of stakeholders.
>
> Finally, the *NSES* and benchmarks provide limited insight into how students’ participation in science practices can be integrated with their learning about scientific concepts; that is, they do not describe how an understanding of scientific concepts needs to be grounded in scientific practice. In addition, although the *NSES* and benchmarks recognize the importance of the first three strands of science learning, each strand is described separately, so the crucial issue of how the strands are interwoven and how they support each other is not addressed.
>
> Although there is a solid research base that supports the premises of organizing science around core concepts, one should be mindful that few studies have examined children’s

> learning of core concepts over multiple years. So questions about what the optimal set of core concepts are, how they should be distributed and organized over the grades, and how to link together instruction across the grades are as yet unanswered. It is, however, very clear that future revisions to the national science standards—and the subsequent interpretation of those standards at the state and local levels and by curriculum developers—should dramatically reduce the number of topics of study and provide clear explanations of the knowledge and practices that can be developed from kindergarten through eighth grade."

Overall, we find that the MN physics standards are reasonably aligned with the original "content" topics in the National Standards. However, their implementation through the different grade levels leaves much to be desired. There is little spiraling back to the same topic with more depth over time. Having benchmarks for a specific grade level, instead of a band of grades, is inappropriate and a practice at variance with recommendations and most other state standards. The assigning of progress through physical science is sporadic and in some cases developmentally inappropriate. Much essential chemistry has been more or less left out of the standards altogether. In both chemistry and physics, the essence of the science, its process, is completely missing. MN standards are not aligned with the current recommendations of the National Academy which originated, along with the AAAS, National Standards. Standards must emphasize the hierarchical nature of the ideas in physical science, its big ideas, its relationship to reality via laboratory experiences, a recognition and remediation of student misconceptions about the physical world, and the process of problem solving. In addition, it is extremely important that all standards documents be reviewed by and independent group of experts in physics education and chemistry education for scientific correctness and specificity of language that will not let them be misinterpreted in light of common misconceptions. There are factual errors and misleading statements in all of the existing standards documents that we have examined.

The reporting of assessments used to evaluate student competencies in the physical science standards must provide useful feedback to schools and teachers to facilitate progress in student learning. This means reporting performance by sub-standard and cognitive level at a minimum.

Finally we examined the statement:

"The student will be able to explain how scientific and technological innovations as well as new evidence can challenge portions of or entire accepted theories and models including but not limited to cell theory, atomic theory, theory of evolution, plate tectonic theory, germ theory of disease and big bang theory."

We find this statement seriously flawed. Science is a process of continuous progress in understanding. A scientific theory is a complex web of consistent models held together with many different types of measurements. Students must have confidence in what we know in order to understand science and its limitations and to contribute to that progress. Science is indeed only an approximation to truth that is continually being refined. New information and new models might affect the domain over which a theory is applicable but is unlikely to affect that theory within the domain in which it is well tested. For example, special relativity and quantum mechanics are more fundamental than Newtonian mechanics and required one of the largest intellectual leaps in the history of science. However, Newtonian mechanics is a valid theory for most of our everyday experiences. It is the basis of most engineering and is still taught in the schools. Intellectually it remains the basis upon which we build relativity and quantum mechanics. In a similar way “cell theory, atomic theory, theory of evolution, plate tectonic theory, germ theory of disease and big bang theory” are and will remain valid scientific theories in the domains for which they have been tested. New measurements or models will continually lead to their refinement and might show that these theories cannot be applied to new domains for which no measurements exist.

Attachment 1 – An example of a deconstruction of problem solving into content that can be continuously learned in K-12.

(Possibly appropriate grade level)

(3 – 12) Describe, using appropriate language, the situation communicated

- a) In a written passage
- b) By a verbal communication
- c) In a pictorial representation
- d) From an observation

(3 – 12) Make a pictorial representation of the situation including all features that are specified.

(5-12) Refine the question being asked about that situation so that it can be answered with the tools and knowledge available. Write down the refined question.

- a) Decide what knowledge from outside the situation might be applicable
- b) Decide what features of the situation are relevant and what are not.
- c) Differentiate between questions that can be answered and those that can not.

(4 -12) Explain how the answer to the refined question resolves the question about the situation.

(4 – 12) Identify basic principles that might be relevant to answering the refined question.

(6 – 12) Identify the constraints that might be relevant in answering the refined question.

(6 – 12) Identify the assumptions necessary to answer the refined question.

(6 – 12) Make a simplified picture, diagram, or graph describing the essentials of the situation that might be needed to answer the refined question.

(6 – 12) Make a rough guess at the answer to the refined question and write down the justification for why this guess is reasonable.

(7 – 12) Write down a logical chain of reasoning that leads from the general principles, constraints, and assumptions to the answer to the refined question.

(6 – 12) Decide on mathematical symbols to represent quantities that might be needed to answer the refined question. Identify which symbol represents the answer to the refined question.

(7 – 12) Using those symbols, write down mathematical expressions (equations) that represent the principles, constraints, and assumptions that might be relevant to answering the refined question.

(7 – 12) Write down a plan of how to use the mathematical expressions to arrive at an answer to the refined question. Determine if there is enough information to answer the refined question.

(7 – 12) Execute the plan and arrive at an answer to the refined question.

(8 – 12) Use techniques such as estimation and dimensional analysis to determine if your answer is unreasonable.

(9 – 12) If the answer is unreasonable, decide on a procedure to find the mistake in your solution.

Attachment 2 – Model of a simple revision of an existing MN physical science standard.

GRADE 9–12
II. PHYSICAL SCIENCE
C. Energy Transformations

Existing:

Standard: The student will understand energy forms, transformations and transfers.

Benchmarks
1. The student will know that potential energy is stored energy and is associated with gravitational or electrical force, mechanical position or chemical composition.

2. The student will differentiate between kinetic and potential energy and identify situations where kinetic energy is converted into potential energy and vice versa.

3. The student will differentiate between AC and DC current.

4. The student will describe the production, storage and transmission of electricity.

5. The student will be able to describe physical and chemical changes in terms of the law of conservation of energy.

6. The student will compare and contrast the amount of energy released through chemical reactions and nuclear fission and fusion.

7. The student will describe the risks and benefits of fossil fuels, renewable sources and nuclear power as sources of usable energy.

8. The student will describe applications of the different wavelengths of the electromagnetic spectrum.

9. The student will describe energy, work and power both conceptually and quantitatively.

Revised model:

Standard: The student will be able to state the principle of conservation of energy and apply it, both quantitatively and qualitatively, to any situation and system including specifying: the energy of a system before and after an interaction, any transformations of energy within that system, and any energy transfers in or out of that system.

Benchmarks
1. The student will be able to identify whether or not there is a potential energy in a given situation depending both on the system that is chosen and the type of interaction within that system.

2. The student will be able to choose a system for which there is a potential energy associated with an appropriate gravitational, electrical, mechanical, or chemical interactions.

3. The student will differentiate between kinetic and potential energy and identify situations where kinetic energy is converted into potential energy and vice versa.

4. The student will be able to use the principle of conservation of energy to identify the primary energy transformations and transfers that describe the production, storage and transmission of electricity.

5. The student will be able to use the principle of conservation of energy in the description of physical and chemical changes.

6. The student will be able to quantitatively estimate the energy transfers from common mechanical, electrical, chemical, and nuclear processes.

7 and 8 are inappropriate.

9. The student will be able to solve quantitative problems using the principle of conservation of energy. These problems should involve the concepts of system energy such as kinetic and potential energy and energy transfer such as work and heat as well as the rate of energy transmission, power.

Report of the Life Science Subgroup

As a life science subgroup, we approach the questions of the Science Readiness Working Group through the lens of what we thought are the most important concepts in life science for K-12 students. While it is impossible to condense all of the age-appropriate approaches to teaching these concepts, we thought it helpful to prepare a short list of what we would expect students to understand at the completion of their K-12 education and prepare to enter post-secondary school or work. A list of these concepts (or big ideas) follows:

- Evolution explains both the unity and diversity of life.
- All life uses the same general classes of macromolecules (carbohydrates, lipids, nucleic acids, and proteins).
- Living things are composed of cells that form the basic structure and perform the basic functions of life.
- Life, from individual cells to ecosystems, requires a constant input of energy to remain organized.
- Living things display varying and profound degrees of interdependence from the cellular to the ecosystem levels.
- Organisms grow, reproduce and develop in predictable ways governed by information encoded in sequences of DNA known as genes.
- Genes are passed from one generation to the next. The orderly passage of this genetic information explains observed patterns of inheritance.
- Mutation causes changes in the DNA. Natural selection, acting upon variation produced by mutations, allows populations to adapt to their environments.

Overarching problem:
Before looking at how well the standards prepare students for postsecondary institutions, we need to first look at the number of students who don’t finish secondary education so cannot enter postsecondary schools. Looking at the data available at http://education.state.mn.us/MDE/Data/Data_Downloads/Student/Graduation_Rates/index.html combined with the report “Cities in Crisis, A Special Analytic Report on High School Graduation” (C.R. Swanson, 2008), a serious issue that should take precedence to any standards is how to keep students in school. Looking at the data from our largest school districts (representing ~14% of our K-12 population), 2005-06 graduation rates are 66.08% from Minneapolis Public Schools, 80.33% from Saint Paul Public Schools, and 91.15% in Anoka-Hennepin. From our schools with high-risk populations, we see 43.01% from Cass Lake-Bena and 50.91% from Red Lake. These statistics represent a significant number of lost students. We realize that this group is not tasked with looking at this issue, but we argue that failure to acknowledge this, and consider how state standards might play a role in what is a complicated issue, would be short-sighted. We know that the Minnesota Office of Higher Education is working on measurements (accountability) of our educational enterprise in the state, so it would be good to have them involved in discussions of the standards group.

It is not sufficient for a strong future that our best students do well, it is critical that all our students do well.

The rest of this document considers those students who do graduate.

Overall conclusions:

Teacher quality is more important than the standards

Students are not ready for college for other reasons than what they have achieved in science standards

Minnesota's science standards should mirror national standards

Science standards and their implementation and assessment should focus on broad concepts and higher order thinking skills

Well-designed standards provide integration between subjects.

Question 1. a) How well do Minnesota's K-12 standards in science reflect the science readiness expectations of postsecondary institutions in Minnesota and around the country? b) What are the differences? Please include reference citations to support your analysis.

State standards do not prepare students for college:

There is a disconnect between what is needed for a student to be "college ready" and what the standards typically address (refer to David Conley's report on "Toward a More Comprehensive Conception of College Readiness", 2007.) In this report, Dr. Conley notes that "Because college is truly different than high school, college readiness is fundamentally different than high school competence." This is an important point (well-developed and supported in this report) that must be considered if we think we can reach college-readiness through implementation of state standards that stress factual knowledge.

Similar viewpoints are expressed in "Standards for Success – Natural Sciences" (CEPR: AAU and Pew Charitable Trusts) where it is noted that the readiness and ability to learn are paramount to success in college – and not dependent on learning the "facts".

Assessments in high school should measure higher thinking skills (critical thinking, problem-solving) rather than factual knowledge that is soon forgotten.

Can we measure readiness specifically in the life-sciences?

One way to measure if Minnesota's K-12 standards meet readiness expectations in postsecondary institutions is to measure the following:
a. what percentage of students entering postsecondary institutions must take remedial work in the topic, and
b. what percentage of students who enter as a major in the field the standards address are successful in completing that major's first course?

The answer to "what percentage of students entering postsecondary institutions must take remedial work in the topic" is 0% at the University of Minnesota since we do not offer any remedial courses in life sciences nor any placement exams. Our only placement exams are in math, chemistry, and the languages. We have assumed this is also true of MnSCU since the only placement tests they list on their admissions website are for reading, writing and mathematics. There are remedial coursework options for life sciences in the high schools (e.g., see the TRiO program, http://www.mntrio.org/new/programs-UB.html), but these do not carry over into postsecondary venues. Thus, we cannot use the measure of remedial coursework to determine if the state science standards meet science readiness in life science per se.

However, we would argue that life sciences depend heavily on mathematics and the physical sciences (particularly chemistry from high school), so that whatever data the physical science subgroup has for readiness would also apply to the life sciences.

The answer to "what percentage of students who enter as a major in the field the standards address are successful in completing that major's first course?" is a difficult one since students may not take the major's first course as freshmen. Thus, the effect of K-12 standards on success in the course is diluted (or overcome?) by subsequent experience in college coursework. In addition, success in a program, including a first course, is heavily dependent on many other factors that the program controls, such as course format, student support services, pre-course preparations, etc. The "gap in time" problem is one that could be addressed by a more integrated approach to presenting material. This approach would also increase mastery of a concept. Finally, an integrated approach would fit well with a plan to have activities that engage students in local research that contributes to state-wide or national databases (e.g., water quality measurements, phenology, other.) Students would truly engage in the scientific process and would be using higher critical thinking skills than are required just learning "facts" from a textbook.

Conclusion

So what is the point here? Our current state standards, with the detailed benchmarks that appear to drive curricular and testing decisions, meet neither the low-end Bloom's taxonomy level of "factual knowledge" nor do they address the higher end skills expected of students who enter college. And since it is the higher end skills that determine success in college, then it is the higher end skills that should drive standards, curricula, and testing.

Question 2. a) How closely do Minnesota's K-12 standards in science align with recognized international and national frameworks developed by scientific organizations and science educators? b) What are the differences? Please include reference citations to support your analysis.

Minnesota's science standards align reasonably well with the CONTENT section (chapter 6) of the National Science Education Standards (see http://www.nap.edu/readingroom/books/nses/) emphasizing important concepts in the life sciences, including evolution, but seem to have missed the major focus on the national standards that is outlined in the other chapters of this national document. For example, Chapter 3, Science Teaching Standards, emphasize teaching just the kinds of skills that the Conley paper said are expected in college-ready students.

For example:

> **"TEACHING STANDARD B: Teachers of science guide and facilitate learning. In doing this, teachers**
>
> - Focus and support inquiries while interacting with students.
> - Orchestrate discourse among students about scientific ideas.
> - Challenge students to accept and share responsibility for their own learning.
> - Recognize and respond to student diversity and encourage all students to participate fully in science learning.
> - Encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science."
>
> **"TEACHING STANDARD E: Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning. In doing this, teachers**
>
> - Display and demand respect for the diverse ideas, skills, and experiences of all students.
> - Enable students to have a significant voice in decisions about the content and context of their work and require students to take responsibility for the learning of all members of the community.
> - Nurture collaboration among students.
> - Structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse.
> - Model and emphasize the skills, attitudes, and values of scientific inquiry."

Again, the point is that the state standards address the details of science, but do not prepare students for college. It is somewhat like learning the shape and color of every puzzle piece, but never learning the purpose of puzzle pieces nor the strategy of putting them together. The result is showing up unprepared for success in a competition for puzzle-completion.

A second point illustrated in the quoted section above is that while national standards stress teacher professional development as a central feature of good standards, Minnesota has no standards for coordinated, mandatory professional development for life science teachers to keep them abreast of the changes in science.

Question 3. a) What changes need to be made to Minnesota's K-12 standards in science to improve alignment with the readiness expectations of postsecondary institutions and national and international science education frameworks? Support each recommendation with one or more reference citations (including page numbers, if it's a document).

We would recommend that the K-12 science standards improve alignment with readiness expectations by addressing the following;

1. Articulate the "gaps" between high school competence and college readiness and focus standards on these. For example, see the "key cognitive strategies" outline (pp. 12-14) and "a definition of college readiness" (pp. 18-20) in Conley's paper.

2. Focus on context not content. This could be accomplished by de-emphasizing (or removing?) benchmarks and emphasizing the general standards and the interrelationships between standards. Assess performance of science skills not science facts (see p. 11, Science Framework for the 2009 National Assessment of Educational Progress.) Our standards/benchmarks should err on the side of less detail, not more. The science facts certainly provide important background information needed to perform well in science skills, but do not represent the framework of science nor do they prepare our students for tomorrow, but rather inculcate them with yesterday.

We note that science standards of other countries (e.g., Finland and Singapore) that are doing well in science according to international studies (e.g., TIMSS and PISA) are quite similar to Minnesota's standards and benchmarks. So perhaps the problem lies not with the standards, but in the implementation. With that question in mind, we note that Singapore's standards do set a different tone than Minnesota's, focusing on skills not facts (see "Science Syllabus Lower Secondary", 2007.)

3. Do not use factual knowledge as a measure of academic and intellectual achievement for K-12 students. Instead, design assessments that measure higher order thinking skills.

4. Incorporate teacher professional development standards into the state standards reflecting the national standards (National Science Education Standards, http://www.nap.edu/readingroom/books/nses/, Chapter 3, Science Teaching Standards.)

Overall conclusions:

Teacher quality is more important than the standards

Teacher quality requires

- Good recruitment
    - Do a better job of recruiting science majors to teaching
    - Raise pay so that it is competitive with other career choices the best and brightest could make

- Good retention
  - Keep pay competitive
  - Support professional growth opportunities
- Substantive professional development
  - Focus should be on teacher professional development to keep them current, well connected to the scientific community, engaged in scientific endeavors

Students are not ready for college for other reasons than what they have achieved in science standards

- College is not Grade 13.
- College population is different than high school (most children go through high school, fewer go to college; college includes the top of the class, students from other states, international students; competition is not limited to grade level peers).
- Success in college requires ability to explain concepts, be adaptable, able to learn on your own.

Minnesota's science standards should mirror national standards

- Focus on teacher preparation and development
- Focus on important science concepts, including evolution, as chosen and developed by the best scientists in our nation (members of the National Academy of Science and others.)
- Better align the balance of concept standards and performance standards.

Science standards and their implementation and assessment should focus on broad concepts and higher order thinking skills

- Science standards are too ambitious, currently covering material over understanding; details over concepts. Change to focus on important life science concepts provided in age-appropriate ways.
- Science standards should include and promote activities that engage students in local research that contributes to state-wide or national databases (e.g., water quality measurements, phenology, other).
- Science standards and assessments should focus on the higher order thinking skills.

Well-designed standards provide integration between subjects.

- Science standards as currently formatted restrict topics to grade levels rather than infuse a large concept throughout all grades (e.g., cell membrane can be covered not only in biology, but also chemistry and physics; similarly basic concepts in chemistry and physics must be reiterated and relied upon when teaching biology).
- Provide opportunities for integrated science projects (link to local inquiry mentioned earlier).

Earth and Space Science Subgroup Report

Question 1:
a) How well do Minnesota's K-12 standards in science reflect the science readiness expectations of postsecondary institutions in Minnesota and around the country? b) What are the differences? Please include reference citations to support your analysis.

Ideas/Recommendations:
A) There is, to our knowledge, no document outlining commonly held expectations for postsecondary readiness in Earth and Space Science, either in MN or nationally. However, the postsecondary Geoscience community in MN is relatively small, and members have frequent opportunity to talk amongst themselves. The most common concern expressed among geosciences faculty in higher education is the lack of exposure to earth science in the high school curriculum. This has been recognized nationally as a factor contributing to the low enrollments in geoscience curricula at postsecondary levels and to the relatively low numbers of geoscience majors across the country; enrollments tend to be higher in states that include earth science in the high school curriculum (see, for example, comments published by the AGI, American Geological Institute, Geoscience Currents #4, available on-line at http://www.agiweb.org/workforce/Currents-004-EnrollmentsbyState.pdf). Considering that the U.S. Bureau of Labor Statistics predicts that job growth for geoscientists will be much faster than average (ranging from 22-25%) between 2006 and 2016 (http://www.bls.gov/oco/ocos288.htm#outlook), the low postsecondary enrollments in the discipline may lead to critical shortages at a time when the country faces serious environmental and energy demands. Job growth in the geosciences during this period is predicted to outpace considerably the growth in the biological and other physical sciences.

With the publication, in the mid-90's, of the "Shaping the Future of Undergraduate Earth Science Education: Innovation and Change Using an Earth System Approach" report (Ireton, Manduca, and Mogk, 1996; available on-line at: http://www.agu.org/sci_soc/spheres/), however, geoscience departments across the country began debating their missions relative to their curriculum. This report stimulated many to embrace the notion that most students taking introductory geoscience courses were enrolled to satisfy general education requirements, rather than enrolled in the entry course to the major. Geoscientists began recognizing their role in serving students enrolled in such "terminal science" courses, and many have earnestly embraced the "science for all" concept, recognizing that the study of the Earth provided great opportunity to help students connect science to their daily lives. It is this group of students (rather than the much smaller population that goes on to become geoscience majors) that we direct the remainder of the comments in this report to – specifically, what knowledge and skills should non-science majors gain in their K-12 curriculum in order to be successful in post-secondary science courses. We assert that these skills, which can be gained through a well-planned study of the earth sciences throughout the K-12 curriculum, will equally serve those students who choose to pursue post-secondary STEM majors and careers. Thus, we target our comments toward the goal of achieving STEM literacy.

The Earth Science subgroup believes that the existing standards focus too heavily on the acquisition of discrete "facts" – the standards themselves read like the table of contents of an introductory text in physical geology, environmental geology, and astronomy combined. There are simply too many topics included to enable students, particularly pre-high-school students (which is where most earth science is covered) to adequately learn to *think* about the Earth and learn to *interpret* what they observe about the Earth, rather than to memorize facts about the Earth (or solar system or universe, in the case of the space science portion of the standards). The Earth itself, never mind the solar system and universe, are far too vast for anyone to understand all that happens.

At the post-secondary level, departments tend to focus their approach to the discipline based upon the expertise of their faculty (see, for example, Drummond & Markin, 2008, Journal of Geoscience Education, v. 56, n.2, p. 113-119; *An analysis of the Bachelor of Science in Geology degree as offered in the United States*). However, most departments agree on a relatively small subset of skills that are critical for success in the discipline. These focus primarily on helping students develop the ability to make observations about the natural world, to collect data about natural processes, and to make inferences about how earth systems operate based on their observations and data. Some departments/programs are heavily field based, while others are based in laboratory analyses. Some are based on more traditional “rocks and minerals” or “earth materials” curricula, while others are based in environmental or “surficial processes” curricula. In all cases, the core skills and critical thinking abilities prevail. The specific content chosen serves as the venue through which the skills are taught or contextualized.

The primary difference we see with the MN standards and the ways that post-secondary programs prepare students is that the MN standards focus on content (facts) and lack requirements that address building student’s ability to observe the Earth and to think critically about what those observations indicate about how the Earth works. Thus, we recommend that K-12 standards (and curricula) focus on critical-thinking development from a systems-based approach. Students need to know more about how to work with data (basic numeracy, arithmetic, proportional thinking, algebraic manipulation, etc.) than they need to know specific content. For example, many introductory physical geology classes introduce students to reading and interpreting topographic maps. In order to do this, students have to be able to understand how to use a ruler, read and work with scale (1 map unit is equivalent to X earth units), understand conceptually that 2-dimensional maps represent 3-dimensional features in the “real world,” and work with simple fractions and directions. Most students remain challenged by these concepts.

Question 2:
a) How closely do Minnesota’s K-12 standards in science align with recognized international and national frameworks developed by scientific organizations and science educators? b) What are the differences? Please include reference citations to support your analysis.

Ideas/Recommendations:
Minnesota’s K-12 standards in Earth & Space Science include age-appropriate content topics. The benchmarks included in the standards are well aligned with the national standards (and the benchmarks of science literacy). The problem arises in practice when considering when students are exposed to Earth & Space Science during their K-12 curriculum. Most MN students study Earth Science at the 8th grade level, and rarely see it during their high school years, despite the

inclusion of standards targeted at the 9-12 grade levels. We note, however, that the MN standards at grades 9-12 are undifferentiated during these years, and there is evidence that these concepts should be scaffolded during this period (see comments below related to the AAAS Atlas of Science Literacy).

The AAAS Atlas of Science Literacy indicates that students are not ready to tackle complex topics in earth science such as plate tectonics until 8th grade. Basic concepts (benchmarks at grades 6-8 include "the earth first formed in a molten state and then the surface cooled into solid rock", lead into somewhat more complex benchmarks "The interior of the earth is hot. Heat flow and movement of material within the earth cause earthquakes and volcanic eruptions and create mountains and ocean basins.") prepare students to be ready to explore more complex concepts in grades 9-12, such as "the earth's plates ride on a denser, hot, gradually deformable layer of the earth." (from AAAS Atlas for Science Literacy, p 52-53.) However, this concept is often introduced as early as 4th grade in MN, and then not covered again in appropriate depth. If AAAS suggests the introduction of the concept in 8th grade, it should be continued into high school so that students are intellectually mature enough and can better grapple with the integrative nature of this fundamental theory. The Atlas suggests that the term "plate tectonics" should not be introduced until 11-12th grade, after students are both intellectually mature enough and have had sufficient experience with fundamental concepts to be able to think about the earth systematically. Similar concerns can be raised about nearly all strands within the existing Earth & Space Science standards.

A recent report (Hoffman & Barstow, 2007, *Revolutionizing Earth System Science Education for the 21st Century*, TERC Center for Earth and Space Science Education) outlines 7 fundamental areas critical to Earth & Space Science education. These are: Earth as a Dynamic System; Space-Age Perspectives; 21st Century Technology; Inquiry-based Approaches; Ocean Literacy, Atmosphere, Weather, and Climate; and Environmental Literacy. This report "grades" each of the 50 states on how well Earth science standards incorporate these forward-looking perspectives and approaches to K-12 Earth Science Education. In all strands except inquiry-based approaches and ocean literacy, MN falls in the lower tier of states, with standards either failing to address key perspectives or doing so only indirectly. More significantly, MN is one of only a handful of states scoring this poorly in the aggregate (see pages 17-39 of the report, available on-line at: http://www.oesd.noaa.gov/noaa_terc_study_lowres.pdf).

Question 3:
a) What changes need to be made to Minnesota's K-12 standards in science to improve alignment with the readiness expectations of postsecondary institutions and national and international science education frameworks? Support each recommendation with one or more reference citations (including page numbers, if it's a document).

Ideas/Recommendations:
The MN Earth and Space Science standards lack an overarching framework that provides teachers (and other readers) with a contextual understanding of the relevance of the discipline and the materials included in the standards. The Earth & Space Science workgroup was particularly concerned that this omission led to an excessive focus on learning facts rather than on integration of material from a systems approach. We were particularly captivated by the

approach taken in the Massachusetts standards, in which MA provides prefatory comments that give a framework for interpreting the content via the overarching goals and approaches – these may provide some insight into the contextual considerations for the learning activities selected by the teacher, and that relate to the students' developmental levels, and then provide a "what it looks like in the classroom" vignette to help the teacher understand how to implement these standards.

These prefatory comments can indicate the 100,000 foot view of why earth science is important to learners, how it can help students prepare for 21st century challenges, and how it can help students connect to other disciplines (whether in science or elsewhere). (See pages 19-20 of MA standards and page 27). Alternatively, the Colorado state standards take an approach in which they identify in the standards the general concept followed by examples that give specifics of the detail expected in the classroom. In each case, however, the standards were general enough to allow the teacher (or school, district, or curriculum) some flexibility in what content was used to develop the skills included in the standards.

The earth sciences are important because they provide a window into other sciences and mathematics, as well as the liberal arts, particularly because the earth sciences connect to myriad aspects of students' daily experiences. Because the nature of the Earth Sciences is so fundamentally integrative, they can connect to all other school-based curricula and to all aspects of life. In addition, study of the earth sciences help students develop critical thinking skills, in part because they offer opportunities to grapple with non-unique solutions drawn from incomplete data sets.

The Earth Sciences provide connections to environmental problems and interactions, which, in turn, provide opportunity to apply what students observe and have learned to the solution of problems that they identify (via the news) and thus can lead to adaptable thinking needed to approach unknown problems later in life.

The Earth Sciences provide connection to the social sciences: geography –where people live and why they live there; political systems – regulation of natural resources, management issues; social issues – the rights of individuals versus rights of society (water rights, wetland management, coal extraction); and economic issues -- oil, natural resources, mining, etc. As such, they provide a powerful means by which to integrate the K-20 curriculum and help students understand that a decision in one area should be informed by data from multiple dimensions because the impact can be far reaching.

The American Geological Institute (AGI) addresses the question "Why Earth Science?" simply, by noting it's "Because we live on Earth." They go on to say that "nearly everything we do each day is connected in some way to Earth: to its land, oceans, atmosphere, plants, and animals. The food we eat, the water we drink, our homes and offices, the clothes we wear, the energy we use, and the air we breathe are all grown in, taken from, surround, or move through the planet." (available on-line at: http://www.agiweb.org/education/WhyEarthScience/Why_Earth_Science.pdf; or on a video on YouTube at: http://www.youtube.com/watch?v=jxbIJH4fTYo)

The Earth Sciences provide a unique opportunity to help students learn to think systematically. A systematic flow throughout the K-12 curriculum (standards), rather than coverage of topics, can help students build both content knowledge and cognitive development. The Earth & Space Science Subgroup recommends changing the MN standards to more explicitly approach earth & space science from a systems approach. An example may be helpful: students are typically introduced to rocks somewhere around grades 2-4, and to volcanoes in grade 4. By grade 8, these fundamentals can help students understand that the earth formed from a molten state and that heat comes from within the interior of the planet. Heat flow within the earth leads to earthquakes and volcanic eruptions (AAAS Benchmarks for Science Literacy). Finally, in high school, students can then build upon their understanding of convection to understand plate tectonics, and more importantly can begin to build connections between this example and others. We might ask "where else can we see examples of heat flow?" and draw students into physics or other earth science examples, or move to space and consider why Mars is geologically "dead."

Rather than their present factual focus, the Earth and Space Science subgroup recommends that the standards be revised to focus on the "big ideas" of Earth and space science. These ideas should be introduced in early grades and build throughout the curriculum to enable students to understand their nuances and complexities and interconnectedness within the geosciences and between the geosciences and other disciplines. A list of "big ideas" in Earth and space science developed specifically for K-12 education has been developed by the TERC and the American Geological Institute as part of the Earth Science By Design project, with support from the NSF. The complete list of ideas appears as an appendix to this report and is available online at: http://www.esbd.org/resources/big_ideas.html. This list contains 25 concepts that form a framework for K-12 study across the scope of the Earth and space sciences. The list separates ideas into strands (the Earth system, the geosphere, the hydrosphere, the atmosphere, the biosphere, space science, and the nature of Earth science).

The MN standards lack connection to "place." One of the greatest strengths of the study of Earth Science is that it can be made uniquely relevant to students by observing their natural world and connecting their study to their world. Minnesota has such unique and variable geology that students can't help be curious about where they live. The Earth and Space Science subgroup, therefore, recommends that the earth science standards reflect and are able to adapt to local geologic features and phenomena so that students can connect science to every-day life; the standards should capitalize on Minnesota's unique geology – whether it be the Mississippi or Minnesota rivers, ancient rocks in central MN or the north shore, the lake country of northern MN, the bluff country of southeastern MN, or glacial geology and the impact of glaciers on shaping the landscapes, etc. Each region of the state has its own unique geology which can motivate students to understand and explore their world. We find it ironic that the existing standards and curricula cover oceans in great depth and yet barely mention glacial geology, which has had such profound impact on shaping MN. The Earth and Space Science subgroup recommends that the coverage of earth science at the 8th grade level in MN should be directed at engaging students in the observation of their (local) world, giving students the opportunity to take what they see in their daily life and connect it to something bigger. Thus, 8th grade Earth Science should focus more on MN geology (beginning from a relatively local perspective and then broadening out to cover other unique areas of the state), and far less on plate tectonics. 8th grade Earth Science should take an earth-systems approach, and build from direct observation and evidence to bigger pictures (weather may be a good topic in this regard, in that it is relatively straightforward to go from direct observations to bigger currents and then to the biggest systems that support their direct observations; maps and data are readily available). This will require elimination of the "science as factoid" approach, and instead move to the incorporation of an "earth-is-a-dynamic-system" approach that looks at data and Earth processes through a variety of lenses. At the high school level, students should be challenged to move beyond the basic concepts to the bigger picture, perhaps by exploring the chemical nature of the Earth, differentiation of materials, and how these contribute to the development of unifying theories like plate tectonics.

The Earth & Space Science subgroup recommends that MN Earth and Space Science standards should recognize that the geologic record provides evidence in support of evolution. The concept of evolution should be integrated in the earth science standards (and not just in the life science strand). Specifically, study within the earth sciences enables learners to connect the concept of "deep time" (vis-à-vis earth history) with evolution in ways that are divorced from the life science strand.

Finally, the Earth & Space science subgroup recommends the inclusion of earth science careers in the earth & space science standards. Many students fail to recognize the viability of the earth sciences as a career path. Recent reports from the Bureau of Labor Statistics suggest that we will need an increasing number of earth scientists to deal with the challenges of the 21st century (ranging from energy development and climate change to resource development and management, and environmental cleanup). Job growth in the geosciences is anticipated to be between 20-25% by 2016, substantially outpacing the anticipated growth in the biological sciences (only 4%), physicists (7% anticipated growth), and material scientists (9% anticipated growth). (For reference, see: http://msn.careerbuilder.com/Custom/MSN/CareerAdvice/ViewArticle.aspx?articleid=1281&cbRecursionCnt=2&cbsid=ae37418003b240239fb93a6bf69be500-266486534-w9-6). Being more explicit about the Earth Sciences in the high school curriculum may lead to greater awareness of potential career paths, but we wonder whether the standards themselves might be explicit about potential careers.

Appendix I: The Big Ideas in Earth & Space Science
(Copied directly from the Earth Science By Design project available online at:
http://www.esbd.org/resources/big_ideas.html)

The Big Ideas in Earth and Space Science

Earth and Space science include many specific facts, theories, and questions, but among these, scientists and educators have identified a certain small set as the "big ideas" that organize the intellectual domain. The National Science Education Standards (NRC, 1996) is the best and most succinct statement of these ideas. The Benchmarks for Science Literacy (AAAS, 1993) are another. Texbooks, state curriculum frameworks, and local curricula are other attempts to establish frameworks for what should be taught.

In this project, we have attempted to synthesize and distill these statements into a single, compact, and defensible list. We have identified what we consider to be the major ideas in Earth and space science that are worth "uncovering" by middle and high school students. The list of 25 concepts on the following page is the result of this work. It is meant not as a final and authoritative list, but rather as a workable framework for organizing what students should spend time studying.

It is our intention that this list serve as the organizing framework for the teaching resources that we are gathering on this web site and for the units that teachers and staff create as part of this project. We welcome your comments and thoughts.

The Earth System

1. Earth can be conceived as an interacting set of processes and structures composed of the atmosphere, geosphere, hydrosphere, and biosphere.
2. Radiation, conduction, and convection transfer energy through Earth's systems.

The Geosphere

3. The geosphere includes the lithosphere, the mantle, and the dense metallic cores.
4. The surface of Earth has identifiable major features--land masses (continents), oceans, rivers, lakes, mountains, canyons, and glaciers.
5. The movement of Earth's lithospheric plates causes both slow changes in the earth's surface (e.g., formation of mountains and ocean basins) and rapid ones (e.g., volcanic eruptions and earthquakes).
6. Earth's surface is built up and worn down by natural processes, such as rock formation, erosion, and weathering.
7. Physical evidence, such as fossils and radioisotopic dating, provide evidence for the Earth system's evolution and development.

The Atmosphere

8. The atmosphere is a mixture of gases with suspended solids and liquids.

9. Radiant energy from the sun creates temperature differences in water, land, and the atmosphere which drive local, regional, and global patterns of atmospheric circulation.

10. The atmosphere exhibits long-term circulation patterns (climate) and short-term patterns known as weather--storms, hurricanes, and tornadoes.

The Hydrosphere

11. Water cycles through the atmosphere, hydrosphere, geosphere, and biosphere.

12. Circulation patterns in the oceans are driven by density differences and by exchange of momentum with the atmosphere.

13. Liquid water in great abundance makes Earth unique among the planets of the solar system.

The Biosphere

14. Life is pervasive throughout the Earth system--in the atmosphere, the hydrosphere, and the lithosphere.

15. Life appeared early in Earth's history and has been intimately involved in the nature of the Earth--i.e. composition of the atmosphere, weathering, carbon cycle, and rock cycle.

16. The biosphere both shapes and is shaped by the physical environment.

17. Human beings have a unique, large, and growing impact on Earth systems.

Space Science

18. The Earth exists in the solar system, in the Milky Way galaxy, and in the universe, which contains many billions of galaxies.

19. The sun, the Earth, and the other planets were formed in a few hundred million years between four and five billion years ago.

20. The relative position and movements of the earth, moon, and sun account for lunar and solar eclipses, the observed moon phases, tides, and seasons.

The Nature of Earth Science

21. Earth scientists use representations and models, such as contour maps and satellite images to help them understand the Earth.

22. Scientists use quantitative, qualitative, experimental and non-experimental methods of scientific inquiry to understand the Earth.

23. Earth scientists make an assumption of uniformitarianism, that the processes that shaped the Earth in the past are the same processes we observe today.

24. Technological advances, such as seismic sounding and satellite remote sensing, advance Earth science knowledge.

25. As in all scientific disciplines, knowledge in Earth science is subject to revision.

History and Nature of Science Subgroup Report

The history and nature of science subgroup's recommendations are based on a review of the National Science Education Standards, the *Benchmarks* of the AAAS Project 2061, selected state and international standards, engineering standards and the experience of the high school and college faculty members of the subgroup. The engineering standards were specifically included because the Minnesota State Science standards currently include elements of engineering in the History and Nature of Science strand.

Intent of the Science Standards:

The subgroup's recommendations are based upon the following premises.

1. **Baseline expectations.** The overall set of standards should be the *baseline* or *minimum expectations* that every student in Minnesota should know and be able to do. Subgroups of students may have higher expectations but the standards should be the minimum expectations for all students.

2. **College and work ready.** The science standards should be crafted so that students meeting the minimum expectations will be able to succeed in an entry level science course in colleges and universities and/or have the requisite skills, knowledge and habits of mind so that they can be successful in an entry level position in a technical or industrial career.

General Recommendations for all Science Standards:

The following are recommendations for the Science Standards as a whole. The history and nature of science does not exist as a separate course in Minnesota's high schools. These standards need to be embedded in the various science curricula. These recommendations should help bring this about and make the standards teachable, relevant and assessable.

1. **Reduce the number of standards.** There should be fewer standards and benchmarks.

2. **Science should be interwoven with other areas of study.** Science should be put into the context of students' lives and the world around them. Students should be able to identify the scientific principles underlying events and objects that affect their everyday lives, the interconnections between the scientific fields, and how the understanding and application of these principles have changed and continue to change our lives.

3. **A few big ideas rather than many details.** Standards should be organized around a limited number of big ideas in order to show the interconnectedness of the natural world. Tying standards together around major concepts will lead to students developing a greater depth of understanding than using an encyclopedic approach or listing of facts.

4. **Focus on critical thinking.** The focus of the standards ought to be on *critical thinking* and *scientific literacy* rather than on memorization and recall, although we recognize that there will be elements of factual information that are necessary for students to develop their critical thinking ability and scientific literacy.

5. **Work for scientific literacy.** In order to develop scientific literacy, students must develop an understanding of how science works. This includes testing scientific validity based upon observation, reliable sources, naturalistic causes, experimentation, and rules of logic.

6. **Relationship between hypotheses, experimentation, laws, and theories.** Students need to develop an appreciation for how science actually works and the distinction between hypotheses, laws, and theories. They also must understand the distinction between popular cultural understandings of these terms and scientists' understanding. Scientific theories are complex constructs based upon myriad factual observations, known relationships and laws, and models based on logic and naturalistic causes. They are not lightly modified and only refined when there is compelling evidence, as filtered through peer review.

7. **Scientists learn by what does and *does not* work.** Students need to recognize that science is a series of ongoing attempts to get to ever greater approximations of how the natural and engineered world works.

8. **Standards need a balance of content and process.** Science must be learned through a combination of content and process, a balance between these two approaches needs to be created. The application of science principles to meet human needs leads to a deeper understanding of science principles.

9. **Standards should be organized by "bands" not specific grade level.** The standards need to be "banded" by groups of grades rather than specific to a certain grade level (e.g. K-2, 3-5, 6-8, 9-12). This will allow for greater flexibility and consistency with state assessments.

Specific recommendation for History and Nature of Science standards:

1. **Include more <u>overt</u> focus on process.** Students need to demonstrate *how* science is done; that they are able to formulate hypotheses, manipulate instruments, make observations and measurements, trouble shoot experiments, analyze data, critically analyze conclusions, propose next steps, and communicate findings.

2. **Imbed standards in context.** Whenever possible the History and Nature of Science standards need to be incorporated as part of teaching other science standards rather than taught as stand-alone concepts, ideas, or skills. Learning science in the context of applications that address everyday life and the major challenges facing the world is motivating and makes learning science relevant. We suggest that the History and nature of

Science standards remain as discreet, stand alone standards so as to provide direction regarding how science is actually done and consequently alluding to how it should be taught. To bolster this expectation, there will need to be additional direction provided through expectations regarding curricular development, instructional strategies, assessment expectations, and professional development opportunities.

3. **An experiment that does not work is not a failure.** Students and teachers need to learn to be comfortable with interpreting unexpected experimental findings. Inquiry is messy and may lead to ambiguous results. Ambiguity drives further exploration, refining interpretations; this is how science works.

4. **Engineering is closely related to science.** An assumption guiding these suggestions is that technology and/or engineering standards will be included in the scientific enterprise substrand of the History and Nature of Science strand. It is important for students to understand both the process of doing science and the application of science (engineering), and the difference between them. Engineering standards should be integrated into Minnesota's Science Standards in ways that will drive interest and passion, demonstrate to students across the spectrum of abilities that they can have an influence on the technology of their future, and will result in a much more motivated, savvy, intellectually curious population – equipped with the skills and attitudes to be innovative in all aspects. This can be done by using a finite set of topics as a guideline. The Corporate Member Council of the American Society for Engineering Education has developed guidelines for K12 education that focus on five dimensions:

    1. engineering design
    2. connecting engineering to science, technology & mathematics
    3. nature of engineering
    4. communication and teamwork
    5. engineering and society

    The latter have been incorporated into the New Hampshire K-12 Science Literacy Curriculum Framework for students to develop the ability to apply these ideas and skills. The National Academy of Engineering lists twenty 20th Century engineering advancements based on science and fourteen 21st Century "grand challenges". These applications would help students understand what has been accomplished and some key problems to be solved.

    Students of today are technologically sophisticated, using the Web, iPods and cell-phones, etc. but lack the intuitive knowledge that comes from building and fixing things that give context for the importance of STEM subjects. Learning how science has been applied and how engineering has assisted in scientific discovery provides a rich motivator for students to learn more about the history of science and the people who have made these significant advances. These issues can, with thought and creativity, be integrated into existing programs and linked to existing standards without creating additional work.

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