AC 2011-524: IMPLICATIONS FOR MATERIALS SCIENCE AND ENGINEERING (MSE) OUTREACH EFFORTS OF EVOLVING DESIGN STANDARDS FOR ELEMENTARY EDUCATION

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Implications for Materials Science and Engineering (MSE) Outreach Efforts of Evolving Design Standards for Elementary Education

Introduction

The recently awarded National Science Foundation project, Science Learning through Engineering Design (SLED) is one of nineteen targeted Math and Science Partnerships (MSPs) focused on science education and one of four MSPs focused on elementary education[1]. Several states, including Massachusetts[2-4], Indiana[5] and Minnesota[6], have established engineering design-based standards that have potential implications for effectively engaging elementary school teachers and students with content related to materials science and engineering. Thirty-nine states, the District of Columbia and the U. S. Virgin Islands, have also adopted the Common Core State Standards, which set common expectations for English Language Arts and Mathematics, providing a context for eventually including science standards that may contain engineering design[7]. Authentically engaging teachers and students with content that transforms science and math education requires that higher education faculty with interest in developing elementary level activities understand teachers' orientations to the engineering design process. They should also understand the context within which teachers teach the content, develop standards-based curricula, and most importantly, how students learn through design. Because physical science standards typically include materials science content, the addition of engineering design to elementary education curricula may pose important opportunities for the materials science and engineering (MSE) disciplinary community.

One critical aspect of the SLED MSP project is the development of grade level appropriate activities that effectively engage teachers and students such that math and science education is enhanced. Members of the SLED partnership seek to develop activities that support the new Indiana Science Standards[5], which include a substantial component of design as an overriding principle and science content that has been revised to incorporate literacy in science, technology and engineering. Teams of interdisciplinary science, technology and engineering faculty, elementary school pre-service and in-service teachers and graduate students are and continue to be actively engaged in creating and optimizing SLED activities for use in partner schools. This paper addresses and discusses implications of prior work on introduction of MSE disciplinary content for K-12 education, including nanotechnology, in the context of existing and evolving standards for math and science education at the elementary level and discusses strategies for developing MSE-related content for these grade levels.

Background on the Status of K-12 Engineering Education

When most engineering educators discuss K-12 education they are likely considering development of content for students at the secondary level. Even if activities include a range that reaches the elementary school level, teachers may be expected to find their own pathways for simplifying or adapting the activities or the activities may be conducted as a departure from the planned math and science curriculum. In a recent assessment of K-12 engineering education curricula by a committee from National Academy of Engineering (NAE) and National Research

Council (NRC) on K-12 Engineering Education, Katehi, Pearson and Feder[12] described three "aspirational" principles for K-12 engineering education that can be summarized as:

1. Emphasize design
2. Utilize "Developmentally-Appropriate" mathematics, science and technology concepts
3. Promote modern concepts and skills of good citizens.

They also documented shortcomings of the existing K-12 engineering education curricula that they reviewed:

> "The treatment of key ideas in engineering, such as constraints, optimization, and analysis, is much more uneven and, in some cases, suggests a lack of understanding on the part of curriculum developers"[12]

In the full report, the NAE/NRC Committee[8] provides summaries, reviews and observations on five of the eight identified elementary education level curricula, noting the characteristics and nature of each. One of these curricula, Engineering is Elementary® (EiE) from the Museum of Science, Boston (reference) is designed to enhance understanding of the contributions engineers make to society and interest in engineering careers, but it is also strongly focused on a particular five step design sequence, "Ask, Imagine, Plan, Create, Improve."[8] Although aspects of what is put forward as design are included in each of the curricula, the interpretations and approaches were found to be quite different. Clearly, a universal concept of engineering design may not be forthcoming, but the breadth of interpretations for just this aspect of the curricula demonstrates the disparate status of K-12 engineering education and curricula that include engineering design.

In their findings and recommendations, the NAE/NRC Committee described the development of systematic linkages between engineering design and scientific inquiry and furthermore, posited these connections as supportive of improved student learning (p. 157)[8], Central to the SLED partnership are the team's purposeful attempts at establishing and reinforcing the relationships between design and inquiry while building conceptual understanding in science and math. Having made a comparison to the process of scientific inquiry and engineering design in terms of constraints, modeling, optimization and systems understanding, the committee also applied these considerations to their review of K-12 curricula.

K-12 Materials Science and Engineering Education

In the context of materials science and engineering the NAE/NRC Committee[12] reviewed the curricular content from the EiE program that is targeted for MSE and the Materials World Modules (MWM). The EiE unit intended to represent MSE, "A Sticky Situation: Designing Walls" is rooted in Earth science and the use of natural materials to design structures. It does help share the principle that design is an aspect inherent to everyday applications, not just advanced technology, while also helping students consider structures and strength. With the exception of content related to manufacturing of bricks and synthesis of mortar that might be related to traditional areas of ceramics, this EiE unit does not naturally bridge students to broader areas of MSE.

The MWM program consists of interdisciplinary materials science content was first originated beginning in 1994 by Professor Robert Chang of Northwestern University through National Science Foundation support[12]. The purpose of these modules was to enrich science literacy at the high school level. Additionally, the modules offer some opportunity to enhance scientific inquiry by having students engage in engineering design. Topics of the nine completed, assessed and published modules include sport materials, biosensors and food packaging with a few more at various stages of development and field testing. MWM reportedly been used by over 40,000 students in 48 states with extensive field-testing.

Materials Science and Engineering Connectivity to State-based Design Standards for K-12 Education

An increasing number of states have incorporated technology, engineering and engineering design into K-12 standards following the longtime leadership of Massachusetts, which first introduced elements leading towards engineering design following legislation passed in 1993[3]. While Massachusetts has continued to act in implementing standards and assessment that respond to that legislation, both Indiana and Minnesota have recently added elements to their science standards that clearly require engineering and engineering design content beginning at the elementary level. These states have introduced these standards at a time wherein a National Academies' "Committee on Standards for K-12 Engineering Education"[9] has concluded that U.S. national content standards for engineering education are "not now warranted". The lack of consensus on grade level engineering content, absence of guidelines and sufficient research for development of instructional materials and no existing, comprehensive survey on K-12 engineering education were all factors that lead to the committee's conclusions. Nevertheless, efforts in individual states are shaping the contexts from which engineering education standards may eventually be derived.

The Massachusetts science standards are explicitly framed as a "Science and Technology/Engineering Curriculum Framework".[4]   The learning standards based on Technology/Engineering begin to thread through every level of the curriculum at the pre-kindergarten level and are explicitly tied to an eight step "Engineering Design Process"[4];

1. Identify the Need or Problem
2. Research the Need or Problem
3. Develop Possible Solutions(s)
4. Select the Best Possible Solution(s)
5. Construct a Prototype
6. Test and Evaluate the Solution(s)
7. Communicate the Solution(s)
8. Redesign[4]

Every level of these standards includes two "Central Concepts" based on "Materials and Tools" and "Engineering Design"[4]. At the grades 3 to 5 levels the central concepts are given as

1. Materials and Tools: Appropriate materials, tools, and machines extend our ability to solve problems and invent.

2. Engineering Design: Engineering design requires creative thinking and strategies to solve practical problems generated by needs and wants.[4]

Throughout the Massachusetts science standards this pairing of materials to engineering design provides a fertile context for problems derived from an interdisciplinary spectrum of materials science and engineering topics. These standards rely strongly on mechanical properties for grade levels wherein abstract understanding of how bonding and atomic arrangements may lead to materials properties. At the middle school level the Materials and Tools elements include consideration of specific classes of materials and materials processing and the Engineering Design elements are upgraded to include iteration and constraints.

The 2010 Indiana Science Standards[5] include "Process Standards" which expresses the processes and skills of how students do science. These standards: "The Nature of Science" and "The Design Process" overlay the science content standards and appear at every grade level from K-12. At the 5th grade level Indiana process standard The Design Process is

> As citizens of the constructed world, students will participate in the design process. Students will learn to use materials and tools safely and employ the basic principles of the engineering design process in order to find solutions to problems.
>
> Identify a need or problem to be solved.
> Brainstorm potential solutions.
> Document the design throughout the entire design process.
> Select a solution to the need or problem.
> Select the most appropriate materials to develop a solution that will meet the need.
> Create the solution through a prototype.
> Test and evaluate how well the solution meets the goal.
> Evaluate and test the design using measurement.
> Present evidence using mathematical representations (graphs, data tables).
> Communicate the solution including evidence using mathematical representations (graphs, data tables), drawings or prototypes.
> Communicate how to improve the solution.[5]

The fourth of four distinct areas for the Indiana "Content Standards," "Science, Engineering and Technology," includes a tie-in to materials science such that students are expected to determine the properties of and uses for natural and man-made materials[5]. Together, engineering design and engineering are in both the Process and Content Standards. At higher grade levels, materials science-related content is most frequently found in the Content Standards of Physical Science and Earth Science and at times implicitly (degradation processes, sustainability) in Life Science.

Minnesota's approach[6] has some strong similarities to Indiana's. They explicitly define a "Strand" of the curriculum as the "Nature of Science and Engineering", which includes a "Sub-strand" called "The Practice of Engineering". Minnesota emphasizes that this strand is to be embedded within teaching, learning and assessment in the three other strands, Physical Science, Earth and Space Science, and Life Science. This has a similar impact on the Minnesota standards to that made by the Process Standards used throughout the Indiana standards. At the second grade level Minnesota defines this standard as students understanding that, "Engineering design is the process of identifying a problem and devising a product or process to solve the problem. This standard carries with it a specific benchmark expecting students to recognize a tradeoff that lies at the root of MSE, "Describe why some materials are better than others for making a particular object and how materials that are better in some ways may be worse in other ways"[6].

An Example of Elementary Level Application of MSE Concepts that Include Design

Wendell and Lee[13] offer a clear pathway towards authentic engineering design in a MSE context, coupled with assessment, at the third grade level. Their study employed clinical interviews and assessment of student work on nine students who worked on tasks that involved materials selection coupled with engineering design. The materials selection followed preliminary activities wherein the students were allowed to explore materials properties through physical tests of compressive strength, heat transfer and sound absorption. Graphical representations of test results and terminology tied to materials performance (insulating, absorbing, strong) were also employed. Wendell and Lee described their use of engineering design as

" . . . one kind of authentic activity that requires the use of both practices and content knowledge related to materials science. We consider design as the activity of creating or proposing plans for a product that will solve an open-ended and ill-structured problem."[13]

Wendell and Lee developed two student tasks- the design of a sturdy stepstool and an insulated pet habitat, by extracting their own expectations for elementary level materials science content that enables engineering design through steps that can be paraphrased as

1. Property testing of materials
2. Matching materials properties to an application
3. Selecting materials possessing specific properties
4. Recognizing extensive properties (mass, weight, volume) and understanding that intensive properties (color, opacity, conductivity, ductility) may be characteristic to specific types of materials
5. Mechanical properties tied to structural applications
6. How an object may have different characteristics than its constituent materials[13]

Wendell and Lee[13] reported changes in students' approaches to materials science such that the

> ". . .results indicate that elementary students can learn to recognize and test intensive properties even if they cannot generate mechanistic explanations for those properties."

The students in this study may not have known the explanation, but the apparently understood that there was an underlying cause behind differences in material performance, a concept rooted at the heart of MSE.

An Opportunity for Connecting MSE Disciplinary Content to Engineering Design

The SLED project disciplinary faculty are developing a spectrum of student activities that enable interdisciplinary content to be folded into the engineering design contexts described above. One potential strategy for disciplinary educators is to find ways to retune and adapt existing disciplinary-related activities targeted for higher grade levels so that they can be introduced to grades three to six. This requires developing approaches for mapping the standards and learning objectives for particular elementary school grade levels to the engineering discipline. As seen in the Massachusetts, Indiana and Minnesota curricula, the presence of materials science within the science content as well as the role materials play in engineering design may offer the MSE discipline an important place in these efforts.

One set of K-12 engineering design educational materials that has apparently not been reviewed by the National Academies are the TryEngineering (TryEngineering.org)[14] materials introduced in 2007 with sponsorship from IBM, IEEE and TryScience. TryEngineering has an extensive list of lesson plans that can be sorted based on age range and topic area. The lesson plans include mapping to particular national and international education standards. Although the TryEngineering website is substantially tied towards helping define and introduce engineering career pathways, the lesson plans are designed for teachers to implement directly in their classroom. Table 1 outlines the suggested TryEngineering lesson plan titles that intersect ages eight to twelve that fall into the category “Properties of Materials.” In the columns the respective content on elementary level applicability of Engineering Design, Materials Science Content and adaptability to use for Materials Selection are subjectively rated as High, Moderate or Limited. Engineering design content is rated based on the real connectivity to standards on engineering design listed by the TryEngineering lesson plan, the materials science content is rated by the language employed to describe the materials and their properties and the materials selection potential is rated by the feasibility of adapting the lesson to include materials selection. Capobianco and Tyrie[15] used and assessed the Candy Bag lesson at the fifth grade level, although it has not yet been adapted to include MSE concepts of materials selection as described by Wendell and Lee[13].

Table 1 *TryEngineering.org[14] Ages Eight to Twelve Lessons Related to Properties of Materials*

Lesson	Engineering Design	Materials Science Content	Materials Selection Potential
Design and Build a Better Candy Bag	High	High	High
Can You Canoe	High	High	High
Engineer a Dam	Moderate	Moderate	Moderate
Design a Dome	High	High	Moderate

Classroom Paper Recycling	Moderate	Limited	Limited
A Century of Plastics	Moderate	High	Limited
Exploring at the Nanoscale	Limited	Moderate	Limited
Build Your Own Robot Arm	High	Limited	Limited
Eeeek- A Mouse	Moderate	Limited	Limited
Engineer a Cane	High	Moderate	Limited

Conclusions

Certainly many other K-12 materials exist and may be already have been adapted or are readily adaptable to the elementary level, but with the current context of rapidly evolving engineering design MSE educators may have an unprecedented opportunity to put forward successful approaches that further recognition and understanding of the discipline.

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1.3 Materials Science versus Materials Engineering. 5.Â Materials engineers design the structure of a material to produce a predetermined set of prop-erties on the basis of structure-property relationships. They create new products or systems using existing materials and/or develop techniques for processing materials. Most graduates in materials programs are trained to be both materials scientists and materials engineers.Â Task 1. Add your notes in the column on the right. AC approx., ca. AT at. no. at. wt. avg. b.p. c., cu., cub. cath. cc cf. (conferre) C. of C. co. cont(d). ctr. DC Dept. dup. e.g. (exempli gratia) esp. est(d). etc. (et cetera) ex. f., ft. hor. i.e. (id est) in., ins. Professor of Materials Science and Engineering at Johns Hopkins University.Â In the area of reactive materials, Weihs began by developing sputter deposited, reactive multilayer foils as model materials for studying phase transformations and as local heat sources for soldering and brazing components. In 2002, he took a three-year leave of absence from Johns Hopkins to commercialize the foils as co-founder and CEO of Reactive NanoTechnologies (RNT). After raising two rounds of venture funding and growing the company to the point of first commercial sales, he returned to active duty at Johns Hopkins in 2005. However, he stayed on part time at RNT as CTO until the company Materials Science and Engineering A provides an international medium for the publication of theoretical and experimental studies related to the load-bearing capacity of materials as influenced by their basic properties, processing history, microstructure and operating environment. Appropriate submissions to Materials Science and Engineering A should include scientific and/or engineering factors which affect the microstructure - strength relationships of materials and report the changes to mechanical behavior. Please be advised that the Aims and Scope for the journal has recently been updated.