122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Seattle Making Value for Society

Paper ID #11942

Work in Progress: How Next Generation Engineering Design Standards are Interpreted and Applied by Various Stakeholders

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Dr. Stephen J Krause, Arizona State University

Stephen Krause is professor in the Materials Science Program in the Fulton School of Engineering at Arizona State University. He teaches in the areas of introductory materials engineering, polymers and composites, and capstone design. His research interests include evaluating conceptual knowledge, misconceptions and technologies to promote conceptual change. He has co-developed a Materials Concept Inventory and a Chemistry Concept Inventory for assessing conceptual knowledge and change for introductory materials science and chemistry classes. He is currently conducting research on NSF projects in two areas. One is studying how strategies of engagement and feedback with support from internet tools and resources affect conceptual change and associated impact on students' attitude, achievement, and persistence. The other is on the factors that promote persistence and success in retention of undergraduate students in engineering. He was a coauthor for best paper award in the Journal of Engineering Education in 2013.

Prof. James A Middleton, Arizona State University

James A. Middleton is Professor of Mechanical and Aerospace Engineering and Director of the Center for Research on Education in Science, Mathematics, Engineering, and Technology at Arizona State University. For the last three years he also held the Elmhurst Energy Chair in STEM education at the University of Birmingham in the UK. Prior to these appointments, Dr. Middleton served as Associate Dean for Research for the Mary Lou Fulton College of Education at Arizona State University for 3 years, and as Director of the Division of Curriculum and Instruction for another 3 years. He received his Ph.D. in Educational Psychology from the University of Wisconsin-Madison in 1992, where he also served in the National Center for Research on Mathematical Sciences Education as a postdoctoral scholar for 3 years.

Jim's research interests focus in the following areas where he has published extensively: Children's mathematical thinking; Teacher and Student motivation in mathematics; and Teacher Change in mathematics. He is currently developing methodologies for utilizing the engineering design process to improve learning environments in Science, Engineering and Mathematics. He has also written on effective uses of educational technology in mathematics and science education as a natural outgrowth of these interests. To fund his research, Jim has garnered over $20 million in grants to study and improve mathematics education in urban schools. He just finished a $1.8 million research grant to model the longitudinal development of fractions, rational number and proportional reasoning knowledge and skills in middle school students, and is currently engaged in a project studying the sustainability of changes in urban elementary teachers' mathematics practices. All of his work has been conducted in collaborative partnerships with diverse, economically challenged, urban schools. This relationship has resulted in a significant (positive) impact on the direction that partner districts have taken, including a significant increase in mathematics achievement in the face of a rising poverty rate.

Ms. Kendra Rae Beeley

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Background/Framework

Within the relatively new Next Generation Science Standards (NGSS), the Engineering Design component is, if not the most intimidating for K-12 teachers, certainly the most dissimilar appearing from the previous National Science Education Standards (NSES).

This is an exciting time in science education, as it has been 19 years since the release of the NSES. This is also an exceptional opportunity to investigate how stakeholders respond to the new engineering standards, as 13 states have adopted the NGSS thus far. Understanding the supports, barriers, and mechanisms that facilitate interpretations and implementation is extremely important in order to execute NGSS' Science and Engineering Practices (SEPs) and Disciplinary Core Ideas (DCIs) of Engineering Design effectively.

In the final chapter of *Framework for K-12 Science Education*[1], the authors urge that it is imperative to establish a research agenda that focuses on "developing a better understanding of how national and state level standards are translated and implemented . . . and how they eventually change classroom practice" (p. 311). That was the goal of this study.

Because research in the area of interpreting and applying engineering design standards in K-12 settings is still in its infancy, literature from science standards and general academic standards is drawn upon. Research focused on K-12 academic standards has largely fallen into one of two categories: (a) studies that examine alignment between, and gaps among, content standards with various elements such as textbooks, assessments, and certification requirements,[2,3,4] and (b) reports of how standards have impacted teachers' attitudes and practices.[5,6] Yet, in short supply are studies examining the actual systemic processes of science standards being received and enacted. In fact, there is a paucity of research on the role of policy in science education in general.[7]

Generally, it has been shown that a new set of content standards results in sluggish change. Often what occurs is that teachers do attempt to make changes based on the new standards, but implement what are considered ineffective versions of the reform.[8] Evidence indicates a reason that science and engineering standards reforms do not take hold in many classrooms is because teachers are not provided adequate professional development or the time needed to fully interpret the standards.[9] Strikingly, results of a survey sent to teachers across one state revealed that 25 percent of teachers did not even know about the state's science standards.[10]

One reason teachers do not align practices with standards is because they do not have adequate content knowledge.[11, 12] Fullan[13] delineated four characteristics of change that affect implementation that can be applied to the adoption of new K-12 science and engineering standards: *need, clarity*, *complexity,* and *quality*. *Need* speaks to the degree to which the change is perceived by those faced with the adoption as a needed change. *Clarity* refers to the extent to which the essential features of the science and engineering standards are understood by those adopting. A potential hazard when adopting new standards is to adhere to a false clarity, which may occur if the engineering standards are over simplified or it is assumed that current practices match the needs of the new standards. *Complexity* refers to the extent of change that different individuals will have to undergo to adopt new standards. Finally, *quality* of science and engineering standards adoption can be affected by system-wide and personal attributes, such as adopting new standards only because it is a requirement, thus leading to few resources being applied to support the adoption.

In investigating the responses of Michigan school district policymakers to math and science standards, Spillane[14] noted that districts that provided high support for the implementation devoted a great deal of time to figuring out what the standards actually meant. This entailed not just teachers, but district-level administrators being involved in the sense-making process. This was in contrast to the districts that provided low levels of support where surface-level understandings of the standards were the norm. Spillane observed interesting differences regarding how district policymakers *noticed* the standards. For example, Michigan's high stakes test was used by many policymakers as a way to notice or comprehend the standards. Fundamental change in what counted as mathematical knowledge and scientific inquiry had been objectives for the designers. How this played out among school districts varied considerably and was influenced often by prior experiences as the new standards were often framed and understood through existing schemas. This led to familiar ideas getting attention and more novel ideas being overlooked.

Researchers have often concluded that policies to adopt new standards are not so much implemented, as they are reinvented by individuals and agencies.[15] Therefore, there is a need to focus research on this reinvention process and understand how NGSS engineering design standards are being interpreted and applied.

Methods

This exploratory study used a mixed methods approach to determine how different groups interpret the NGSS engineering design standard and how they believe engineering design should play out in a middle school classroom (grades 5-8). Survey data and short-answer responses were collected from 1) middle school science teachers, 2) science education college faculty (responsible for preparing middle school teachers), and 3) college of engineering faculty. Both groups of faculty teach at Arizona State University, where the study was housed. Each group was comprised of four to six individuals, and they received no incentive or compensation for their participation. The groups represent a convenience sample comprised of faculty and classroom teachers who were already associated in some way with the university.

Data Collection. Participants volunteered to complete the Interpreting Engineering Design Survey (IEDS) online with the only identifying information gathered being their professional role. The respondents were prompted to consider two of the four performance expectations that comprise the middle school component of the Engineering Design strand within the NGSS. Only two of the four performance expectations were selected due to considerations of the time requirements to complete the survey. The two selected were considered by the researchers to pose somewhat indefinite parameters, presented the possibility for multiple interpretations, and were simply the lengthiest of the four performance expectations:

> **MS-ETS1-1**. Students, who demonstrate understanding, will be able to define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

> **MS-ETS1-3.** Students, who demonstrate understanding, will be able to analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

Respondents were provided a link that allowed them to view these performance expectations within the NGSS context. This enabled them to view the other Engineering Design performance expectations, as well as the Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts which the NGSS indicate underpin these performance expectations.

For each of the two performance expectations, participants were prompted to address two key inquiries:

1. Please provide your own plain language interpretation of this performance expectation (i.e., what does it mean?).
2. Provide an example of how this standard could be applied in a middle school classroom (i.e., a lesson, activity, unit).

This second point was left rather open, such that participants did not necessarily have to reference any prior or ready-made lesson plans. The IEDS additionally included questions which prompted the participants to indicate what they felt were the challenges and benefits of implementing these performance expectations into a middle school classroom. Finally, the IEDS prompted participants to indicate what personal experiences they had which most helped them to interpret these performance expectations.

Coding. Respondents' middle school lesson suggestions, to address each of the performance expectations, were analyzed via three systems. First the lesson ideas were coded using a priori coding scheme based on the NGSS Science and Engineering Practices and on the related NGSS Disciplinary Core Ideas for engineering (Table 1). The lesson ideas were assigned one or more of the Science and Engineering Practice codes (SEP-1 – SEP-4) and Disciplinary Core Idea codes (DCI-1 – DCI-3), depending on whether the concept was present. Two reviewers coded the responses independently and met to negotiate differences until full agreement was reached. In some cases, the lessons that the respondents provided did not align well to any of the SEP or DCI elements and were therefore not assigned a code.

The NGSS indicates that the two performance expectations chosen for this study are aligned with particular Science and Engineering Practices and Disciplinary Core Ideas. Specifically, MS-ETS1-1 is linked within the NGSS to SEP-1 and DCI-1. MS-ETS1-3 is linked within the NGSS with SEP-3, DCI-2, and DCI-3. Therefore, it was anticipated that coding of participants' example lessons would load heavily on these NGSS elements, but it was not assumed.

Table 1. IEDS Priori Coding

SEP-1. Asking Questions and Defining Problems – *Define a design problem that can be solved through development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.*
SEP-2. Developing and Using Models – *Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs.*
SEP-3. Analyzing and Interpreting Data - *Extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. Analyze and interpret data to determine similarities and differences in findings.*
SEP-4. Engaging in Argument from Evidence - *Evaluate competing design solutions based on jointly developed and agreed-upon design criteria*
DCI-1. Defining and Delimiting Engineering Problems - *The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.*
DCI-2. Developing Possible Solutions - *A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. Models of all kinds are important for testing solutions.*
DCI-3. Optimizing the Design Solution - *Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.*

Second, the lesson ideas were evaluated to determine the degree to which the lesson was actually workable. To this end, the Practicality and Clarity of Engineering Design – Lessons Rubric (PACED-LR) was developed (Table 2). This yielded an evaluation of the potential for the described lesson to be genuinely developed and transferred to a middle school classroom.

Finally, the classroom examples were examined to assess how they could, if at all, be typified. That is, the researchers wanted to see if the responses could be parsimoniously categorized in a meaningful way.

For the IEDS questions related to the challenges and benefits of implementing the engineering design performance expectations in a middle school classroom, open coding was utilized. Occurrences of regularly stated themes such as time constraints (a challenge) and supporting other science concepts (a benefit) were tallied and examined. A similar approach was taken to categorize and tally the responses regarding the personal experiences which respondents indicated helped them to interpret the performance expectations.

Table 2. Practicality and Clarity of Engineering Design - Lessons Rubric (PACED-LR)

	1	**2**	**3**
Practicality – materials and time	The lesson is not viable nor realistic within the context of materials and timeframe and/or needs to be considerably more intelligible in these areas.	The lesson is somewhat viable and realistic within the context of materials and timeframe and/or needs to be somewhat more intelligible in these areas.	The lesson is very viable and realistic within the context of materials and timeframe.
Practicality – challenge and capacity	The lesson is not viable nor realistic within the context of student cognitive challenge and teacher capacity and/or needs to be considerably more intelligible in these areas.	The lesson is somewhat viable and realistic within the context of student cognitive challenge and teacher capacity and/or needs to be somewhat more intelligible in these areas.	The lesson is very viable and realistic within the context of student cognitive challenge and teacher capacity.
Clarity	The lesson is ill-defined and/or it is not evident how it would be implemented in a classroom.	The lesson is somewhat well defined and/or it is marginally evident how it would be implemented in a classroom.	The lesson is very well defined and it is evident how it would be implemented in a classroom.

Results

SEP and DCI alignment. The example lessons that respondents provided in response to both MS-ETS1-1 and MS-ETS1-3 were found to be quite broad in nature and specificity. For example, four respondents provided concrete, albeit traditional, lesson ideas that involved having students building bridges or towers and analyzing collected data to determine an optimal design. On the other hand, some responses were less precise such as having students “design a solution for a problem of a local community.”

Each lesson idea was scrutinized by the researchers and coded as described in the Methods section. A lesson was coded for an SEP or DCI category only if it was evident that the element was clearly present in the lesson. Tables 3 and 4 provide the results of the coding.

Although the NGSS indicate that MS-ETS1-1 is linked to SEP-1 and DCI-1, these particular elements did not resonate strongly among the 15 lesson ideas (Table 3). Only one-third of the lessons were found to address the practice of having students ask questions and define problems (SEP-1). In many lessons it was deemed students were either handed a problem to solve or the lesson did not genuinely involve a problem design at all. Lesson ideas that did not integrate SEP-1 included students reading an article and then discussing the social and environmental impact of the European Extremely Large Telescope, and having students “create a water filter from every day materials, then write a paper about its impact.”

Similarly, the engineering core idea of having students define and delimit an engineering problem (DCI-1) was apparent in only five of the 15 lessons. A lesson which hit this mark was the suggestion for students “to design a bridge given the constraints and affordances . . . and identify any adverse as well as positive results of the design and placement of the bridge.” Conversely, an example of a lesson which did not integrate the concept of defining and delimiting was the broad suggestion for students to “identify a sustainability problem in the school and then be given the task to come up with a plan to solve the challenge.”

The only lesson that addressed both SEP-1 and DCI-1 was the suggested activity of having students design a piece of playground equipment wherein the design criteria included the users, characteristics of materials, safety concerns, cost, durability, and environmental impact.

Surprisingly, five lessons, which were provided to address MS-ETS-1, did not resonate with any of the SEP or DCI practices. An example of an un-coded lesson was the suggestion from Participant #12 for students to “design a recycling system for a school cafeteria.” While the context of recycling certainly does hold potential for a wealth of engineering design problems, as written, the lesson idea does not address any key NGSS components, such as engaging in argument or optimizing a design solution.

Table 3. MS-ETS-1, Alignment of Lesson Suggestions with NGSS Elements

Role	ID	SEP-1*	SEP-2	SEP-3	SEP-4	DCI-1*	DCI-2	DCI-3
EdFac	1		x	x		x	x	
EdFac	4							
EdFac	6							
EdFac	7	x					x	
EdFac	12			x	x			
EngFac	8	x	x	x				
EngFac	10							x
EngFac	11	x						
EngFac	13							
EngFac	14					x		
EngFac	15	x				x		
MST	2							
MST	3	x		x		x		x
MST	5							
MST	9		x	x		x		x

EdFac = College of education faculty member, EngFac = College of engineering faculty member
MST = Middle school teacher, *element is linked to MS-ETS-1 in the NGSS

The lessons that were suggested to address MS-ETS1-3 were more aligned with the anticipated NGSS elements than those that were provided to address MS-ETS1-1 (Table 4). NGSS indicates that MS-ETS1-3 is linked with SEP-3, DCI-2, and DCI-3. Nine of the 15 lessons addressed SEP-3, six addressed DCI-2, and nine addressed DCI-3. Generally, then, respondents were better able to generate ideas that addressed the paradigm of students “analyz[ing] data from tests to determine similarities and differences among several design solutions” (MS-ETS1-3) than they were able to address having students “define the criteria and constraints of a design problem” (MS-ETS1-1). An example of a lesson that integrated all three key MS-ETS1-3 elements was the suggestion for students to “test several different bridge designs to figure out which one is able to support the most weight . . . [and] from these tests they could assemble a new design using the most effective shape, material(s), and method of construction.” Alternatively, a lesson that did not address any of these three elements was the simple suggestion of having students construct scale models of playground equipment.

Table 4. MS-ETS-3, Alignment of Lesson Suggestions with NGSS Elements

Role	ID	SEP-1	SEP-2	SEP-3*	SEP-4	DCI-1	DCI-2*	DCI-3*
EdFac	1			x	x	x		x
EdFac	4			x				x
EdFac	6							
EdFac	7			x			x	x
EdFac	12		x	x			x	x
EngFac	8			x				x
EngFac	10							
EngFac	11			x			x	x
EngFac	13		x	x		x	x	x
EngFac	14						x	
EngFac	15			x				x
MST	2			x				
MST	3							
MST	5				x		x	
MST	9							x

EdFac = College of education faculty member, EngFac = College of engineering faculty member
MST = Middle school teacher, *element is linked to MS-ETS-3 in the NGSS

Practicality and clarity. With a typical middle school science course in mind, the PACED-LR was applied. The researchers found that use of the PACED-LR instrument was very valuable in discerning lessons for their feasibility and replicability in a middle school classroom. In a few cases, although a lesson may have integrated some key SEP and DCI practices, the lesson was considered to involve materials or a timeframe that was beyond the scope of a typical science course or to simply be too vague to invoke an actionable lesson. For example, although Respondent #11’s idea was credited for addressing SEP-1 and DCI-1, the suggested lesson of having students study an environmental problem “and have them form criteria and constraints for the problem” was assessed to be too ambiguous to score well on the PACED-LR.

A Spearman correlation analysis was performed to determine the relationship between the total amount of SEP and DCI practices addressed ($\bar{x} = 1.80$, std. dev. = 1.54) and the average score on the PACED-LR ($\bar{x} = 1.83$, std. dev. = 0.83). Among the 30 lessons, a significant relationship was found to exist between the amount of SEP/DCI practices and the average score on the PACED-LR ($r = .697$, $p < .001$). Essentially, this was interpreted to mean that lessons that were more comprehensive in their breadth and depth (as gauged by the SEP and DCI practices) were more clear and were more appropriately aligned with resources, as well as with middle school student and teacher capacity.

Categories of responses. Following the coding of the lessons and initial discussions, the lessons were re-read by both researchers in an attempt to determine if the lessons could be grouped in a helpful and descriptive manner. Surprisingly, this task was relatively straightforward. The lessons were labelled as belonging in one of the four following categories:

1. Construction Challenge Focused on Optimization (n=8)
2. Construction/Crafts (n=3)
3. Weighing/Analyzing/Reporting Given Data (n=5)
4. Vague and/or Overly Broad (n=14)

Group 1 was comprised of lessons that were aligned to multiple DCI and SEP practices. Lessons in this group involved students engaged with a definable engineering problem wherein it was necessary for students to compare multiple criteria in order to decide on an optimal design. An example of a lesson from group 1 was the suggestion for students to "design a container to minimize the melting rate . . . of an ice cube." This lesson required students to consider rate of energy transfer, insulation materials, heat dissipation materials, and cost of materials. Lessons that were classified into Group 2 only provided indication that students would be constructing and did not specify that students would be further cognitively engaged. Examples of lessons included in Group 2 are the plan for students to construct a water filter and the suggestion for students to build scale models of playground equipment.

Lessons in Group 3 typically followed the format of providing students with data and prompting them to draw conclusions and/or to generate a report. For example, Respondent #2 suggested the lesson of having students use "data tables regarding material strength, material cost, and material durability to choose a material to build an artificial leg."

Group 4 was comprised of the largest number of lessons. Unfortunately, these were all deemed so ambitious that they became unclear or were simply ambiguous. All of the lessons in this group scored low on the PACED-LR. Examples of lessons in this group include the suggestion for students to "develop knowledge of a problem (either real or fabricated) in which they are given the task of finding a solution" and the response of "Given 5 solutions for a problem, prototype and test them and compare criteria values."

Challenges and Benefits. Respondents cited several challenges they foresaw to implementing the Engineering Design performance expectations. Most prevalent among these (n=7) was the sentiment that middle school students were unaccustomed with addressing engineering problems and being tasked with having to negotiate multiple criteria in order to arrive at proposing a solution. Other often cited challenges were the paucity of existing quality exemplars for middle school classrooms (n=4) and that middle school classrooms generally lacked the materials to support in-depth engineering design problems (n=4).

Among the benefits predicted, the respondents were fairly cohesive in stating a value was that engineering design problems would promote deeper and more thoughtful problem solving skills among middle school students (n=13). The next most cited benefit was that the integration of engineering design problems had the potential of bringing science to life for students through the context of real-world problems (n=6).

Experiences. The types of experiences which respondents indicated helped them to understand the NGSS engineering design performance expectations were categorized using conventional emergent coding. Experiences that were cited at least twice are provided in Table 5.

Table 5. Experiences Cited as Helpful in Addressing NGSS Engineering Design

Role	**ID**	Has done engineering research	As a student, experience w/ design	Done similar with K-12 students	Done similar with pre/in-service teachers	Done similar with engineering students
EdFac	1	x				
EdFac	4	x			x	
EdFac	6			x		
EdFac	7				x	
EdFac	12				x	
EngFac	8					x
EngFac	10					x
EngFac	11				x	x
EngFac	13					x
EngFac	14					x
EngFac	15	x		x		x
MST	2		x	x		
MST	3			x		
MST	5			x		
MST	9		x			

EdFac = College of education faculty member, EngFac = College of engineering faculty member
MST = Middle school teacher

Table 5 indicates clearly that respondents are drawing heavily from their experiences as facilitators and as teachers with learners ranging from middle school students to adult learners. Although perhaps not surprising, Table 5 also reveals a grouping of responses based on professional roles. For example, middle school teachers are largely drawing on their experiences with middle school students and college engineering faculty are drawing from their experiences with their engineering students. Only two of the respondents, both middle school teachers, indicated that they were drawing upon experiences *as* students in a professional development environment. Only one of those two respondents indicated that the professional development was specific to NGSS. This provides one clear call for the need for focused professional development for anyone involved in implementing K-12 NGSS engineering design.

Conclusions

The small sample size of this exploratory study precludes sweeping conclusions. However, these data do raise some particular concerns and are robust enough to suggest where attention may need to be focused as states continue to adopt NGSS.

The responses from the sub-groups indicated some noteworthy clustering effects, based on professional roles of college of education faculty, college of engineering faculty, and middle school teachers. The groups generally responded in similar ways when providing ideas in response to MS-ETS-1 (defining criteria and constraints of a design problem). However, the middle school teachers' ideas to address MS-ETS-3 (analyzing data from tests to determine similarities and differences among several design solutions) aligned less often to NGSS elements. This is especially noteworthy for the elements NGSS indicates this performance expectation is linked to: SEP-3 and DCI-3. Again, it is recognized that these small sample sizes prevent any strong supposition, but the pattern is nevertheless noted.

Another notable finding from these data was the scarcity of quality engineering lesson ideas. As noted, approximately half of the lessons were categorized as Vague and/or Overly Broad. Only eight of the 30 lesson ideas encompassed the key factor of engaging students with a design problem focused on optimization. Among these eight, four had a traditional mechanical/civil engineering slant and were centered on building a bridge or tower; two were related ideas from the same respondent regarding minimizing the melting rate of an ice cube; one lesson prompted students to design a piece of playground equipment with strong considerations of constraints; and one challenged students to use iterative processes to build and navigate a robot through a maze. The lesson ideas underscore three important conclusions. First, it is clear that as NGSS is rolled out into more schools, there is a tremendous need for the standards to be accompanied by professional development that allows middle school teachers to learn about specific lessons and units of study that support engineering design. This implies going beyond just encouraging conceptual visions and promoting cognitive engagement, such as argumentation and analysis. Rather, this points to the need to demonstrate feasible classroom activities – something which ASEE K-12 Workshops have been addressing.

Related to this, is the second conclusion that the NGSS engineering design standards can too easily be decoded in an excessively expansive manner. This appears to result in indefinite ideas that are difficult to translate into classroom practice. For example, one respondent provided the lesson idea of students being "given the opportunity to develop several different designs to solve a problem, evaluate these designs, and then identify the good and bad features of these designs." No doubt, robust interpretation of the NGSS engineering design standards into classroom practice is not straightforward. In this respect, it is recommended that providing some well-defined trees will help teachers to see the forest.

Finally, it is noted that the majority of the concrete lesson ideas that were gathered in this study were focused on mechanical and civil engineering. These lessons also typically relied heavily on integration of physics concepts. While it is understood that availability of supplies and readiness of students may lead to these types of emphases, consideration should be given to how these "hard sciences" are sometimes viewed as masculine and can be alienating for many students, especially girls.[16] Efforts to integrate engineering lessons into middle school classrooms should take into account the value of providing a wide range of ideas from multiple engineering disciplines and incorporating concepts from other areas such as geological and life sciences.

Acknowledgement

This material is based upon work supported by the National Science Foundation under Grant No. 1226586.

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