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How Engineering Standards are Interpreted and Translated for Middle School

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Abstract

In this exploratory study we examined the alignment of Next Generation Science Standards (NGSS) middle school engineering design standards with lesson ideas from middle school teachers, science education faculty, and engineering faculty (4–6 members per group). Respondents were prompted to provide plain language interpretations of two middle school Engineering Design performance expectations and to provide examples of how the performance expectations could be applied in middle school classrooms. Participants indicated the challenges and benefits of implementing these performance expectations and indicated personal experiences that helped them to interpret the performance expectations.

Quality of lessons differed depending on the performance expectation being addressed. Generally, 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" than having students "define the criteria and constraints of a design problem." A notable finding was the scarcity of quality engineering lesson ideas. The greatest proportion of lessons were categorized as Vague and/or Overly Broad. It appears that NGSS engineering design standards can too easily be decoded in an excessively expansive manner, thus resulting in indefinite ideas that are difficult to translate into classroom practice.

Keywords: NGSS, standards, policy, engineering standards, middle school, science standards

Introduction

Within the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013), 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) (National Research Council, 1996). This is an exciting time in science education, as it has been two decades since the release of the NSES. This is also an exceptional opportunity to investigate how stakeholders respond to the new engineering standards, as 17 states have adopted the NGSS thus far. Understanding how NGSS will be interpreted and implemented 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* (National Research Council, 2012), the authors urged 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). This provided direction for the current study. We sought to understand how different stakeholders interpret the Engineering Design standards of NGSS.

Related Literature

The Process of Interpreting and Translating

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 was 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 (Bhola, Impara, & Buckendahl, 2003; Georges, Borman, & Lee, 2010; Liu & Fulmer, 2008), and (b) reports of how standards have impacted teachers' attitudes and practices (Donnelly & Sadler, 2009; Sunal & Wright, 2006). 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 (Cheek & Quiriconi, 2011).

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 (Cuban, 1993). This result has been that schools often make first-order changes such as adding new programs or altering the school day or year, but that second-order changes that encompass fundamental changes in teaching and learning are rare (Cuban, 2013). The inertia that often keeps schools from making legitimate progress, versus ongoing changes or tinkering, is tied to misinterpretation of new policies in ways that make them appear more familiar than they actually are (Spillane, 2009). Evidence also 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 (Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2010). 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 (Sunal & Wright, 2006).

Fullan (2001) delineated characteristics of change that affect implementation that can be applied to the adoption of new K–12 science and engineering standards such as *need* and *clarity*. *Need* speaks to the degree to which a change is perceived as a needed change and *clarity* refers to the extent to which essential features of content 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.

In investigating the responses of Michigan school district policymakers to math and science standards, Spillane (2009) 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.

Interpretation of K–12 Engineering Standards

Regarding the context of K–12 engineering education, although a fair amount of literature has been devoted to the efficacy of specific programs that are aligned with state and national standards (e.g., Cogger & Miley, 2012), few researchers have yet examined how engineering standards are interpreted and consequently implemented. Hynes (2012) did examine how domain-specific knowledge of six middle school teachers impacted their understanding and teaching of the engineering design process. Hynes suggested that implemented lessons were representations of teachers' understanding of the engineering design process and found that although during interviews teachers were able to explain engineering practices, such as the cyclical nature of engineering design, their classroom implementation did not always align with these explanations. Whether this was due to misaligned understanding or the curriculum itself was uncertain. Similarly, it has been found that elementary teachers' comfort with integrating engineering design into their classrooms is influenced by familiarity, prior knowledge, and experience (Hsu, Purzer, & Cardella, 2011), as well as by belief about student motivation (Van Haneghan, Pruet, Neal-Waltman, & Harlan, 2015).

These types of findings often lead to researchers rationally concluding that teachers require quality and ongoing professional development. However, this perspective can also be considered deficit model thinking that considers teachers as lacking something which professional development will provide (Phillips & Beddoes, 2013). What is also needed is consideration of how mindsets at the outset affect classroom implementation.

Purpose and Framework

Researchers have concluded that policies to adopt new standards are not so much implemented, as they are reinvented by individuals and agencies (Darling-Hammond, 2005).

Therefore, there is a need to focus research on this reinvention process and understand how NGSS engineering standards are being interpreted and applied. What is particularly important in the sense-making process are first impressions and first translations because these will influence ongoing interpretation and application (Weick, 1995). In the context of educational policy, such as academic standards, Mancinelli (2014) emphasized the importance of first impression processes as mechanisms because they affect how a policy will be implemented.

In this study our intent was to examine first impressions of the NGSS middle school standards by querying individuals in a state where NGSS has not yet been adopted. Several researchers have examined educational policies by scrutinizing how a policy has been understood and implemented long after it has been introduced as dogma (e.g., Spillane, 1996; Spillane, 2009; Smith & Kovacs, 2011). However, we wanted to focus on the early process of interpretation that is the imagining of how standards will play out in a classroom environment. Weick (1995) referred to this early interpretation as "plausible speculation." To that end, this study was designed to collect initial ideas about implementing NGSS middle school standards. There was no intention to prompt participants toward providing the "best" lesson ideas they could create or find. Instead, preliminary conceptions of lesson ideas were valued as useful data representing interpretation. In this framework, an idea for a lesson that emerges after viewing a content standard, is considered a type of representation of a person's sense-making. An individual's process of organizing and translating information into the representation of a lesson can be viewed as a type of representational perspective as defined by Faisal, Attfield, and Blandford (2009).

We also sought to determine if differences among groups could be detected. Specifically, there was interest in examining interpretations from college of education science faculty and middle school science teachers because NGSS would have direct impact on their roles. Additionally, there was interest in learning if interpretations from engineering faculty differed from these first two groups.

Methods

In this exploratory study we 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.

Participants

The three groups were each comprised of four to six individuals who received no incentive or compensation for their participation. Individuals were solicited via email to participate. The emails indicated that the goals of the research were to examine how the engineering design standards were translated into practical applications. As this was an exploratory study, only faculty members from the college of education and the college of engineering from the researchers' university were solicited. This is a large university in the southwestern United States and both of these colleges rank in the top 15 nationally in enrollment. The researchers were familiar with some of the faculty members who were sent email solicitations; however, it was unknown who actually responded. The middle school teachers who were solicited to participate taught at either K–8 schools or middle schools that qualify as Title I schools and are in low socioeconomic neighborhoods.

Data Collection

Participants volunteered to complete the Interpreting Engineering Design Survey online (Appendix) 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 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:

- Please provide your own plain language interpretation of this performance expectation (i.e., what does it mean?).

- 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 so that participants did not necessarily have to reference any prior or ready-made lesson plans. The Interpreting Engineering Design Survey 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 survey prompted participants to indicate what personal experiences they had which most helped them to interpret these performance expectations.

Coding

Responses were randomly assigned a number and identifying roles (i.e., faculty member or classroom teacher)

were removed from printouts which the researchers analyzed. Two researchers did all of the coding. Respondents' middle school lesson suggestions, to address each of the performance expectations, were analyzed via three systems:

- SEP and DCI alignment – priori coding
- Practicality and clarity – rubric scoring
- Categories of responses – emergent coding

1. SEP and DCI alignment - priori coding

In the first coding system, the lesson ideas were coded using a priori coding scheme based on the NGSS Science and Engineering Practices (SEP) and on the related NGSS Disciplinary Core Ideas (DCI) 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. The two researchers coded the responses independently and then met to

Table 1
Interpreting engineering design survey 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 optimal solution.*

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.

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.

2. Practicality and clarity – PACED-LR rubric

Second, the lesson ideas were evaluated to determine the degree to which they were actually workable. To this end, the Practicality and Clarity of Engineering Design – Lessons Rubric (PACED-LR) was developed (Table 2). It is noted that this rubric was created specifically for this project because no established instrument was found that focused on feasibility of a lesson. Therefore, the rubric has face validity as judged by the researchers who have expertise in middle school science classrooms. The same two researchers rated the 30 lesson responses with the PACED-LR. The two researchers first rated each response independently for the three categories of the PACED-LR and then negotiated where there were discrepancies. The initial independent ratings (before negotiation) resulted in 82 percent of scores being in exact agreement. The validity of PACED-LR was further assessed by calculating Cronbach's alpha coefficient across the three scales and for all 30 responses. The internal consistency was found to be high (Cronbach's α = 0.92), thus implying the instrument items measure the same construct.

3. Categories of responses – emergent coding

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. To that end, the lessons were re-read in an attempt to determine if the lessons could be grouped in a helpful and descriptive manner. This process was done in tandem. A constant comparative method was used for this purpose to assign the lessons to emergent classifications.

For the survey 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 inductive approach was taken to categorize and tally the responses regarding the personal experiences which respondents indicated helped them to interpret the performance expectations.

Results

1. SEP and DCI alignment - priori coding

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."

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	x					x	
EdFac	6	x	x	x				
EdFac	7							x
EdFac	12							
MST	2							
MST	3							
MST	5			x	x			
MST	9							
EngFac	8	x						
EngFac	10					x		
EngFac	11	x				x		
EngFac	13	x		x		x		x
EngFac	14							
EngFac	15		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

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	x
EdFac	6			x				x
EdFac	7							
EdFac	12			x				
MST	2			x				x
MST	3							
MST	5		x	x			x	x
MST	9		x	x		x	x	x
EngFac	8			x			x	x
EngFac	10						x	
EngFac	11			x				x
EngFac	13							
EngFac	14				x		x	
EngFac	15							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

Each lesson idea was scrutinized by the researchers and coded as described in the Methods section. A lesson idea was coded for an SEP or DCI category only if it was evident that the element was clearly present. 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 a paper 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."

Only two lessons addressed both SEP-1 and DCI-1. The more concrete of the two suggested an 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." Although 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.

It is also noted, that although the small sample sizes do not allow reasonable statistical comparisons, in response to MS-ETS1 there were some observed differences. Notable was that three of the five responses that did not address any of the SEP or DCI elements were from the four middle school teachers. Although the groups of engineering faculty and education faculty each had one response that did not address any of the SEP or DCI elements, the large proportion of non-alignment with MS-ETS-1 among the middle school responses is conspicuous. As a group,

the engineering faculty were best able to address DCI-1. Of the five responses from the dataset that did address DCI-1, four were from engineering faculty. Overall this indicates that the engineering faculty were more apt to provide responses that involved students addressing design constraints.

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.

Unlike Table 3, differences between groups are less distinguishable in Table 4. All three groups had one response that did not align to any of the SEP or DCI elements. For this engineering standard the engineering faculty did not emerge conspicuously different as they did for MS-ETS-1. Clearly larger sample sizes would facilitate deeper understanding of differences, if any, among groups.

2. Practicality and clarity – PACED-LR rubric.

With a typical middle school science course in mind, the PACED-LR was applied. The researchers found that use of this 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 for MS-ETS-1 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

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 w/ K-12 students	Done similar w/pre/in-service tchrs	Done similar w/ engin. students
EdFac	1	x				
EdFac	4	x			x	
EdFac	6			x		
EdFac	7				x	
EdFac	12				x	
MST	2		x	x		
MST	3			x		
MST	5			x		
MST	9		x			
EngFac	8					x
EngFac	10					x
EngFac	11				x	x
EngFac	13					x
EngFac	14					x
EngFac	15	x		x		x

($\bar{x} = 1.83$, std. dev. $= 0.83$). Among the 30 lesson suggestions, a significant relationship was found to exist between the amount of SEP/DCI practices and the average score on the rubric ($r = 0.697$, $p < 0.001$). Essentially, this was interpreted to mean that interpretations that were more comprehensive (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.

3. Categories of responses – emergent coding.

As stated, following the coding of the lessons and initial discussions, the lessons were re-read by a pair 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:

Group 1: Construction Challenge Focused on Optimization ($n = 8$)

Group 2: Construction/Crafts ($n = 3$)

Group 3: Weighing/Analyzing/Reporting Given Data ($n = 5$)

Group 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 idea 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. Lesson ideas 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.

Lesson ideas 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 having students use "data tables regarding material strength, material cost, and material durability to choose a material to build an artificial leg."

Group 4 comprised the largest number of lesson ideas. Unfortunately, these were all deemed so ambitious that they became unclear or were simply ambiguous. All of the suggestions in this group scored low on the PACED-LR. Examples of lesson ideas 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, Benefits, and Personal Experience

The results thus far characterize respondents' initial lesson ideas. Still lacking are notions regarding what underpins those interpretations. By asking the open-ended questions regarding what individuals saw as the benefits and challenges of integrating engineering design into middle school classrooms, as well as asking about their personal experiences, we were able to form a general picture of positions. Further research that delves deeper into this with interviews will be necessary to fully explicate such ideas, but the following does provide general indication about viewpoints and sources of experiences.

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 indicates that respondents drew 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, based on professional roles of college of education faculty, college of engineering faculty, and middle school teachers. Engineering faculty provided the most NGSS-aligned responses when providing ideas in response to MS-ETS-1 (defining criteria and constraints of a design problem). However, the groups appeared more similar when addressing MS-ETS-3 (analyzing data from tests to determine similarities and differences among several design solutions). That engineering faculty

provided responses that more often involved students defining and delimiting a problem when addressing MS-ETS-1, may simply speak to their familiarity of promoting this type of thinking among college students. More striking was the lack of alignment of middle school teachers' responses to MS-ETS-1 with SEP/DCI elements. Only one of the four middle school teachers provided a response that aligned to any of the SEP/DCI elements when addressing MS-ETS-1. On whole this seems to indicate that professional development for middle school teachers should focus more on engineering design as a process (MS-ETS-1) and acknowledge that having students analyze data from tests (MS-ETS-3) is something which middle school teachers are more skilled.

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.

Related to this, is the second conclusion that the NGSS engineering 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 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. Physics, along with chemistry, is considered a "hard science"

or concerned with physical entities (Heller & Ziegler, 1996; Simms, 2011) as opposed to sciences that are concerned with living entities. While it is understood that availability of supplies and readiness of students may lead to these types of emphases, a possible implication to consider is how physical sciences are viewed as being more masculine than life sciences and can be alienating for many students, especially girls (Hill, Corbett, & St Rose, 2010). 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.

This study provided a general picture of how new engineering standards are translated into plausible speculations; that is, initial lesson ideas. Further research needs to be done in order to drill down deeper and discover the rationale behind interpretations. Understanding the parameters that moderate translation will aid in supporting implementation that is aligned with original intentions. Specifically, research that focuses on interviewing individuals who were involved with authoring NGSS *and* classroom teachers will help us understand how loose or tight the coupling is between policy design and implementation.

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Appendix - Interpreting Engineering Design Survey

- 1. Check your professional role:
  - ___engineering college faculty
  - ___middle school science teacher
  - ___science education college faculty

- 2a. Consider this performance expectation for middle school students from NGSS' Engineering Design component:
  - *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.*

- 2b. Please provide your own plain language interpretation of this performance expectation? (i.e., what does it mean?)
- 2c. Please provide an example of how this performance expectation could be applied in a middle school classroom (e.g., a lesson, activity, unit).
- 2d. What challenges do you see to implementing this performance expectation into a middle school classroom?

- 2e. What are the potential benefits to implementing this performance expectation into a middle school classroom?

- 3a. Consider this performance expectation for middle school students from NGSS' Engineering Design component:
  - *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.*

- 3b. Please provide your own plain language interpretation of this performance expectation? (i.e., what does it mean?)
- 3c. Please provide an example of how this performance expectation could be applied in a middle school classroom (e.g., a lesson, activity, unit).
- 3d. What challenges do you see to implementing this performance expectation into a middle school classroom?
- 3e. What are the potential benefits to implementing this performance expectation into a middle school classroom?
- 4. What specific past experiences (e.g., with engineering, with students, etc.) do you have that helped you to interpret these performance expectations?