122nd ASEE Annual Conference & Exposition

June 14 - 17, 2015

Seattle, WA

Seattle Making Value for Society

Paper ID #13590

# Are We Preparing the Next Generation? K-12 Teacher Knowledge and Engagement in Teaching Core STEM Practices

**Dr. Louis Nadelson, Utah State University**

Louis S. Nadelson is an associate professor and director for the Center for the School of the Future in the Emma Eccles Jones College of Education at Utah State University. He has a BS from Colorado State University, a BA from the Evergreen State College, a MEd from Western Washington University, and a PhD in educational psychology from UNLV. His scholarly interests include all areas of STEM teaching and learning, inservice and preservice teacher professional development, program evaluation, multidisciplinary research, and conceptual change. Nadelson uses his over 20 years of high school and college math, science, computer science, and engineering teaching to frame his research on STEM teaching and learning. Nadelson brings a unique perspective of research, bridging experience with practice and theory to explore a range of interests in STEM teaching and learning.

**Mrs. Anne Seifert, Idaho National Laboratory**

Anne Seifert EdS

INL K-12 STEM Coordinator Idaho i-STEM Coordinator

Anne Seifert is the Idaho National Laboratory STEM Coordinator and founder and executive director of the i-STEM network. She holds a BS degree in elementary education, an MA in Education Administration and an EDS in Educational Leadership. As a 30 year veteran teacher and administrator she has been involved in school reform, assessment, literacy, student achievement, and school improvement. Her current work involves coordinating partnerships with educators, the Idaho Department of Education, business, and industry to raise STEM Education awareness. Anne's research interests include STEM education, inquiry and project-based instruction with the incorporation of 21st Century learning, change practices, and cultural influences on school effectiveness.

**Mr. J. Kade Hendricks, Utah State University**

J. Kade Hendricks is a research assistant at Utah State University where he is also completing a PhD in educational leadership. He has a BS and a MPA from Southern Utah University as well as numerous certifications in administration. He serves as an instructor for Central Christian College of Kansas and advises non-traditional students in their degree completion goals. Kade brings a unique perspective to educational research as his professional background is centered upon at-risk youth and offending adults in the judicial system.

# Are We Preparing the Next Generation? K-12 Teacher Knowledge and Engagement in Teaching Core STEM Practices


**Abstract**

**Background**: Several of the recent reform efforts in K-12 STEM education (e.g. Next Generation Science Standards [NGSS and Common Core State Standards-Mathematics [CCSS-M]) have included significant emphasis on the practices of STEM. We argue that K-12 teachers' ability to effectively engage their students in these core STEM practices is fundamental to the success of potential and current engineering students and their subsequent careers as engineers. Practices such as identifying problems, modeling using mathematics, and arguing from evidence are fundamental processes in engineering. Helping students develop their capacity to engage in these practices early in their education will increase the likelihood of the students applying the practices and developing skills aligned with the work of engineers. We contend that engaging in the practices associated with engineering may increase K-12 student interest and the successful pursuit of engineering as a career because they will find relevance in what is being taught and gain knowledge of the applications of STEM content which will help them develop talents aligned with the work of engineers.

**Project**: In recognition of the importance of being able to apply the practices of science and engineering (NGSS) and the practices of mathematics (CCSS-M) to be successful as an engineer (or a STEM professional), we emphasized the of importance and value of core STEM practices as part of i-STEM - our week-long intensive, statewide STEM professional development (PD) summer institute program for over 500 K-12 educators. During i-STEM, the K-12 educators were exposed to interactive plenary sessions in which keynote speakers walked the participants through the practices using authentic hands-on activities and materials detailing the practices, and STEM professional development providers engaged them in the practices in STEM topic specific "strands" (intensive 25 hour short courses based on themes such as mining, energy, computer science, robotics, transportation, and etc). To determine the impact of the summer institute, we developed and administered an instrument to assess the participants' knowledge and engagement in teaching core STEM practices.

**Pre-Test Results:** Our analysis revealed that before the teachers (N = 347) entered the i-STEM professional development offering they had very limited knowledge of core practices. When asked to list core practices some responded with answers such as, "I have no knowledge of this." and "Give background on rockets, watching videos, building rockets, discuss how and why they flew the farthest, redo and re-fly." and "Not sure what you mean by "practices."" In contrast, when asked to rate their levels of knowledge of the math practices (on a scale of 1 – 10) the average rating was 5.67 (SD = 2.21) and knowledge of science/engineering practices was 2.62 (SD = 2.00). Responses indicated that the teachers rated their knowledge as moderate in math and low in science/engineering and yet they struggled to articulate many of the core STEM practices.

**Post-Test Results:** The immediate post-test of the participants (n = 347) revealed increases in self-reported averaged ratings of knowledge of the CCSS-M practices (M = 6.63, SD = 1.86) and the NGSS science and engineering practices (M = 5.04, SD = 2.03). However, as with the pre-test, these ratings were misaligned with detailed articulation of the practices. Responses to the item asking the participants to list the core STEM practices included statements such as, "I think there is a written explanation as to why things work and the steps broken down and explained." and "Not familiar enough." Regardless many participants indicated that they had a better understanding of the practices after the i-STEM institute.

## Introduction

The increased emphasis on STEM as a component of economic development and competitiveness has mandated increased attention toward STEM in schools [1,2]. There have been movements in response to the mandate that were designed to address the need for increased attention toward STEM education and shift how we teach STEM to K-12. The resulting STEM education initiatives include the Common Core State Standards – Mathematics (CCSS-Math) and the Next Generations Science Standards (NGSS)[3,4]. The anticipated outcome of these STEM education standards is an application or practice-based approach to K-12 STEM teaching and learning. An expected outcome is an increase in the number of students well prepared for post-secondary education and workforce entry. There is also the anticipated outcome of increasing the number of students interested in pursuing STEM careers, particularly in high need areas such as engineering. Thus, educators and policy makers expect that the standards will increase the number of students with STEM talents, as well as, recognize the potential challenges associated with implementing the NGSS and CCSS-Math[5,6,7,8].

A common exercise associated with the consideration and adoption of the new learning standards such as the NGSS and CCSS-Math are efforts to determine how the standards align with currently adopted STEM learning standards. The process of examining the alignment between extant (typically state determined learning standards) and the new learning standards (the NGSS and CCSS-M) is commonly referred to as *cross-walking* (e.g. Irvin, et al, 2012[a]). The goal cross-walking is to determine the extent to which the new STEM learning standard align with the existing STEM learning standards. One possible outcome of the cross-walk is greater understanding of the professional development or resources needed to prepare teachers to teach to the STEM content standards[9].

While the cross-walk has been taking place to examine the content knowledge of the standards, there is evidence to suggest that substantially less attention is being paid toward examining the NGSS and CCSS-Math *practices* – which are the processes that K-12 teachers should engage their students in as they learn the associated STEM content[10]. We contend that the lack of student engagement in core STEM practices is likely to constrain their STEM learning and motivation to engage in STEM opportunities, and their pursuit of STEM degrees and careers. By teaching in ways that engage students in the practices, teachers can increase their students' knowledge of the processes that STEM professionals engage in as they work. We also argue that without teachers embracing and implementing of core STEM practices at high levels in their teaching of STEM content, student knowledge and appreciation for STEM will not be changed through the adoption of the new STEM content learning standards.

Given the potential for gains in student knowledge of the work of STEM professionals, particularly in engineering through engagement in the core STEM practices, there is justification for assuring that K-12 teachers are prepared to and are supported in teaching in ways that engage students in core STEM practices. We maintain that there is a need to offer professional development that enhances teacher capacity to help them shift their teaching to better engage

---

[a] Irvin, P. S., Saven, J. L., Alonzo, J., Park, B. J., Anderson, D., & Tindal, G. (2012). The development and scaling of the easyCBM CCSS elementary mathematics measures: grade 4. Technical Report# 1318. *Behavioral Research and Teaching*.

students in core STEM practices.  Similarly, there is a need to continue to investigate teacher knowledge of, perceptions of, and engagement in core STEM practices.

The focus of our research was to empirically establish the baseline levels of teacher knowledge, perceptions, and engagement in teaching in ways that engage students in the NGSS and CCSS-Math practices.  Through the i-STEM professional development summer institute, we explicitly addressed core STEM practices through a range of activities.  Following the i-STEM professional development institute, we again surveyed the participating teachers to determine the effectiveness of the intervention for increasing the participating K-12 teachers' knowledge, perceptions, and thoughts about teaching core STEM practices.  Our goal was to determine if the i-STEM professional development summer institute was effective for enhancing the teachers' capacity to teach in ways that engaged their students in the NGSS and CCSS-Math practices and are therefore effectively preparing students to be the next generation of STEM professionals.

**Core STEM Practices**

The adopted core STEM practices of the NGSS and CCSS-Math were developed with the intention of bringing authentic alignment between the teaching and learning of STEM with the way that STEM professionals work on problems and projects[3,4].  Unlike the STEM content standards, the practices associated with the NGSS and CCSS-Math have not been widely adopted and recognized as part of what K-12 students need to learn and how K-12 teachers need to teach.  Thus, it is likely that the lack of exposure and engagement with core STEM practice standards as part of the curriculum combined with constrained teacher preparation have left many educators without models, motivation, and knowledge of how to teach STEM content aligned to the practice standards.  Regardless, the practice standards provides authenticity and a pathway to increasing K-12 student knowledge of how STEM related research, projects, and process take place in the workplace, and the post-secondary STEM education community plays an important role in promoting and supporting core STEM practices teaching and learning.

The NGSS science and engineering practice standards were designed to engage students in the practices associated with scientific investigations and engineering design[11].  Thus, the NGSS practice standards are:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information,

Again, the intention of the NGSS practices is to provide a framework for making curriculum and instruction in K-12 science and engineering more purposeful, engaging, and authentic.  The expected outcome of instruction aligned with core STEM practices is greater student engagement and a greater understanding of science and engineering which deemed likely to lead to increased student interest in and pursuit of STEM careers[12].

Similar to the NGSS standards, the CCSS-Math contain standards that parallel the work of professional mathematicians and, perhaps more importantly how other STEM professionals use mathematics to conduct research and solve problems[3]. The CCSS-Math practices are:

1. Make sense of problems and persevere in solving them.
2. Reason abstractly and quantitatively.
3. Construct viable arguments and critique the reasoning of others.
4. Model with mathematics.
5. Use appropriate tools strategically.
6. Attend to precision.
7. Look for and make use of structure.
8. Look for and express regularity in repeated reasoning.

**Teacher Adoption of Innovation**

Teacher adoption of reform initiatives such as the NGSS and CCSS-Math has been challenged by their perceptions of such efforts as being stifling of their creativity and autonomy[13]. Further, many teachers hold perceptions and conceptions of the CCSS-Math that may be negative or inaccurate[14]. The desire of some teachers to maintain a familiar system teaching and learning, a position of conservatism[15], is likely to thwart efforts to embrace core STEM practices and consider new instructional approaches and curriculum choices. Thus, shifting teachers' perceptions and instructional practices likely requires professional development that supports adoption and implementation of innovations such as teaching in ways that engage students in core STEM practices[16].

Given the innovative nature of the core STEM practices when compared to the traditional approaches to STEM education, we argue that there is a need to explicitly expose teachers to the practices and engage them in activities so that they may experience situations that illuminate ideas for and the benefits of teaching to the practices. Further, exposure to the practices empowers the teachers by increasing their knowledge and perceptions of the innovations, thereby preparing the teachers to adopt and experiment with the curriculum and instruction aligned with the practices.

**Teacher Practice and Student Engagement in STEM Practices**

In the Science and Engineering Indicators 2014[17] report, there is an array of status highlights illuminating the current state of multiple aspects of elementary and secondary STEM education that provide insight into the challenges associated with the implementation of the NGSS and CCSS-Math. For instance, the report highlights that 77% of elementary teachers feel very prepared to teach mathematics while only 39% of these teachers felt prepared to teach science. The ramifications for the lack of elementary teacher preparation to teach science is the associated time they spend teaching science. Currently, elementary teachers teach science for less than an average of a half hour per day[18]. The lack of time spent on teaching science and engineering limits elementary students' early exposure to the fundamental STEM concepts and processes and fails to capitalize on STEM as a context for teaching to the broader curriculum.  Thus, elementary students may not develop interest and knowledge of STEM due to lack of exposure.

In contrast, the reported lack evidence of secondary student interest in learning STEM content, which may be due to the nature of the secondary level STEM instruction and isolation of STEM disciplines, which does not tend to foster student curiosity, enthusiasm, or promote the appeal of STEM.  Thus, it is not uncommon for secondary students to perceive STEM courses as irrelevant and boring[17].  The potential for teachers to be performance oriented (focused on grades and getting the correct answer) rather than mastery oriented (focused on developing deep conceptual understanding) in their mathematics and science instruction[19,20,21,22] may further hinder deep student engagement and enhanced learning through core STEM practices.  The lack of student interest in learning STEM and lack of teacher focus on mastery learning is likely to limit secondary student development of an appreciation, curiosity, authenticity and deep knowledge of STEM concepts and activities[23] resulting in diminished engagement in STEM learning, talent development and we posit reduced interest in STEM careers.

The focus on core STEM practices in the NGSS and CCSS-Math shifts the goals in STEM education from getting the correct answer when given a problem, to developing an approach to problem solving applying the practices used by STEM professionals in the workplace.  Further, shifting instruction to align teaching with core STEM practices may liberate K-12 teachers to perceive teaching STEM as efficient and allows for students to develop a wide range of skills that can be applied across disciplines.  However, the shift may encounter the barrier of K-12 teachers' persistence in teaching as they were taught[15, 19], making the implementation of core STEM practices as an emphasis in instruction and curriculum choices a challenge.  Thus, effectively designed STEM professional development for K-12 educators that attends to core STEM practices is likely to be critical to shifting K-12 educators' perceptions, knowledge, and teaching of STEM[24, 25,26].  The shifts in teachers' approaches to teaching STEM is needed to address issues of time and attention toward STEM at the elementary level and issues of student interest in learning STEM at the secondary level.  We believe that due to our explicit focus on core STEM practices, that our professional development summer institute offering is a potential solution to helping K-12 educators shift their instruction and curricular choices to provide opportunities for their students to engage in core STEM practices.

## Methods

### Research Questions

Our research goal was to determine the levels to which the K-12 educators attending our i-STEM summer institute understood and engaged in teaching their students core STEM practices.  We also wanted to determine if the i-STEM summer institute influenced the participants' perceptions, knowledge, and ideas for integrating core STEM practices into their teaching.  We used the following questions to guide our study:

- What are K-12 teachers' commonly held beliefs and knowledge of core STEM practices?

- What are K-12 teachers' confidence in their abilities and the processes used to implement core STEM practices learning opportunities as part of their curriculum?
- Are K-12 teachers discussing STEM practices in their schools and are they expected to teach the practices?
- What influence did attending the i-STEM professional development summer institute have on participating K-12 teachers' knowledge and perceptions of core STEM practices?

We hypothesized that the K-12 educators participating in our i-STEM professional development project would have constrained knowledge of core STEM practices, would not be teaching to the practices, and have few ideas about how to integrate the practices. Therefore, the educators would benefit from professional development that explicitly addressed the STEM practices and engaged them in activities and discourse based on the practices. We also hypothesized, that through the i-STEM activities and discourse, the teachers would experience gains in core knowledge, perceptions, and ideas for integration of core STEM practices into teaching and learning.

**Participants**

We had over 500 participants in our i-STEM summer professional institute; however, we were able to match the pre and post institute survey data for only 347 participants. Thus, our sample was composed of 347 K-12 educators who were on average 43.59 years old (SD = 10.34) and had been working in K-12 education for an average of 12.90 years (SD = 8.79). The participants were composed of approximately 57% elementary teachers, 27% middle school teachers, and 16% high school teachers. The educators reported an average level of comfort teaching STEM of 5.49 (SD = 2.34), which being on a 10 point scale, suggests a middle level of comfort. The participants also reported moderate level average of 5.01 (SD = 2.52) with regard to their engagement in promoting STEM education in their communities. Of our 347 participants, approximately 44.4%, had participated in a prior i-STEM PD summer institute.

**Data Collection**

We used a repeated measures design[27] surveying participants before the institute, provided the institute (intervention), and again surveyed the participants. The K-12 educators who voluntarily registered for the institute were emailed a link to our surveys and instructed to complete the survey prior to attending the summer institute. At the end of the institute, we sent another email with the post-institute survey link and gave the participants 3 weeks to complete the survey.

All data collection was anonymous, so we asked the participants to select a 5 digit code (the last 5 digits of any phone number) that they would easily recall and use in the surveys so that we could pair the pre and post survey data. Data collection took place online using SurveyMonkey.

**Measures**

Our team collaborated on the development of the surveys that we used in our investigation. To gather our participants' professional characteristics, we used a demographic survey that we have been refining over the five years of the project. We also developed 4 other instruments composed of combinations of selected and free response items to gather an array of other STEM education related information. The first survey assessed the participants' knowledge, perceptions and engagement with core STEM practices. The second survey assessed the participants' use of instructional technology. The third survey assessed the participants' engagement and knowledge of place-based STEM. The fourth survey assessed the participants' knowledge and teaching of 21st century skills. For our current report, we used the data from our core STEM practices survey and the demographics survey.

We choose to frame our core STEM practices survey around the NGSS and CCSS-Math practices because we anticipated that the participating K-12 educators would have limited knowledge of core STEM practices and even more constrained knowledge of the professional practices of STEM professionals. Further, we expected that the teachers who do teach core STEM practices would most likely to be able to relate to the NGSS and CCSS-Math practices and therefore would find NGSS and CCSS-M practices related questions relevant and attainable. We also selected to use the NGSS and CCSS-Math practices as a frame because the standards' practices are integral to the preparation and work of engineers and other STEM professionals. We created free response items to gather the participants' knowledge of the practice data using prompts such as "In your own words define the "practices" of the CCSS- math," and "How do you assess your students' development of CCSS-Math practices?" We created several Likert-like 5 and 10 point scale items to assess the participants' perceptions of the practices which included items such as, "Rate the confidence in your ability to effectively integrate the CCSS - Math practices with the science content you teach." and "We discuss the CCSS-Math practices in faculty meetings." The 22 items in the practices survey were evenly divided to gather data related to the CCSS-Math and the NGSS. The full survey can be found in the appendix.

**Professional Development**

Our current report is about the work in our 5th year of i-STEM a large scale statewide STEM K-12 educator professional development project which has evolved from year to year, but has maintained focus on integrated STEM, education-business partnerships (with many state-wide partners including but not limited to Boise State University, Idaho National Laboratory, Micron, and the Idaho State Department of Education) project-based learning, and use of local resources to support STEM teaching and learning. i-STEM took place in six sites throughout Idaho. Our six one week-long i-STEM professional development summer institutes involved hosting 42 STEM business professional or teacher-led STEM integrated *strands* (short courses of about 20–25 hours of integrated STEM PD contact time for 15–20 teachers) distributed across the 6 locations in the state and within a reasonable proximity to the majority of rural communities. The topics for the strands were diverse and included foci such as energy, mining, transportation, water, food and space. The K–12 educators voluntarily participated and self-selected into the strands (depending on space available). The strands were designed to build STEM education capacity by increasing participant knowledge of STEM content, STEM pedagogy, STEM core practices, best instructional practices, and leadership. The outcomes varied slightly based on the strand theme or context but all engaged in a project based integrated STEM approach.

The i-STEM institutes attracted 100–150 participants in each of the 6 regions. The strands curriculum included field trips, speakers, and multiple activities that explicitly addressed core STEM practices. The balance of 40-45 hours was filled with keynote speakers, other all group activities (e.g. family engineering – for more information please see http://www.familyengineering.org/), and planning. The institutes were week-long and took place in the summer. The theme for the summer institute we are reporting was *core STEM practices*, which were explicitly addressed in the strands and plenary sessions. For one college credit, all participants created a lesson plan, identified the STEM practices addressed in the lesson, and included a classroom assessment plan.

## Results

### Knowledge and Beliefs of STEM Practices

Our first research question asked, "What are K-12 teachers commonly held beliefs and knowledge of core STEM practices?" To answer this question, we started out by examining the participating teachers' pre-institute responses to our item requesting them to explain core STEM standards. We scored their responses in relationship to the participants' abilities to describe the practices using a rubric that was scaled from 0 – "No Response" to 4 – "Expert Knowledge." We scored our participants' responses to both the NGSS and CCSS-M knowledge items (see Table 1). Our analysis revealed higher levels of knowledge for the CCSS-Math practices than the NGSS practices. However, we also found that greater than 80% of the responses were reflective of minimal or less levels of understanding of both the NGSS and CCSS-M practice standards.

Table 1. *Responses, Frequency and Percentages of Pre-Institute Explanations of CCSS-Math and NGSS Practices*

| Code and Score | CCSS-Math Frequency & Percentage | CCSS-Math – Example Response | NGSS – Frequency & Percentage | NGSS – Example Response |
|---|---|---|---|---|
| **0 – No Response** | 5 (1.65%) | "N/A" | 22 (8.06%) | "Not Applicable" |
| **1 – No Knowledge** | 60 (19.80%) | "Using real life situations in math" | 129 (47.25%) | "Have not heard of NGSS" |
| **2 - Minimal Knowledge** | 194 (64.03%) | "Teaching students to understand numbers and their relationships instead of algorithms." | 114 (41.76%) | "Conduct experiments. Gather and synthesize information. Develop models" |

| | | | | |
|---|---|---|---|---|
| **3 – Moderate Knowledge** | 42 (13.86%) | "The practices of CCSS math focus on developing mathematical thinking by teaching problem solving skills, making connections and leaps of understanding, as well as developing a strong mathematical language where students prove their thinking process. Running parallel to this, is the teaching of computational skills and procedures, providing students with the essential tools they need to incorporate math into their daily life in a useful way." | 8 (2.93%) | "The students will learn how to use inquiry by first asking a question and then planning how to carry that out. Using the data they will think about how to explain what happened and arrive at a conclusion. This can involve using prior knowledge from previous experimentation as well." |
| **4 – Expert Knowledge** | 2 (0.66%) | "The CCSS-Math practices are processes that students use to become proficient in math. These practices asks students to use problem-solving skills such as logical reasoning (does it make sense); it requires that students don't given up (persevere); use a variety of models and strategies; pay attention to precision and to communicate (defend or argue) their reasoning to others." | 0 (0%) | NO REPRESENTIVE RESPONSES WERE AVAILABLE |

We used a similar 0 – "No Response" to 4 – "Expert Response" coding scheme for several other STEM practices related items that included: 1) the participants listing the practice standards; 2) how the teachers communicated the practice standards to their students; 3) how the teachers created opportunities to engage students in the practices; and 4) how the teachers assessed their students' learning of the practices. We present our coding results below in graphic form (See figure 1). Similar to the response distributions for the participants' knowledge of the practices (see Table 1), we found that the majority of the participants provided responses that were coded as minimal or less. Another trend that continued, was there were more complete and knowledgeable answers provided for the CCSS-Math practices than for the NGSS science and engineering practices.

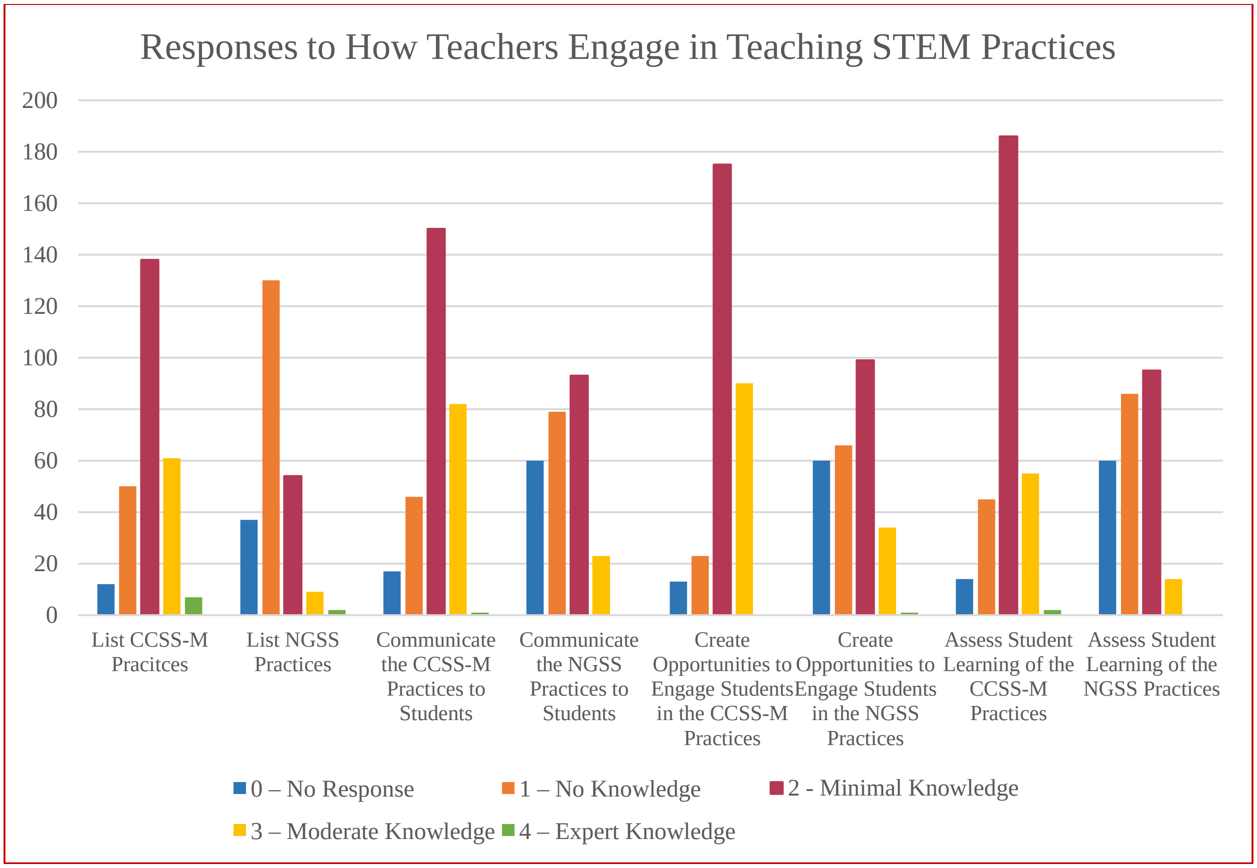


*Figure 1.* The frequency of teachers coded responses to our free-response items associated with teaching the CCSS-Math and NGSS practices.

When asked to rate their level of knowledge of the practices of the CCSS-Math and the NGSS (on a 10 point Likert-like Scale), the participants indicated moderate knowledge of the CCSS-Math practices (M = 5.67, DS = 2.22) and relatively low levels of knowledge of the NGSS practices (M = 2.62, SD = 2.00). When we compared the participants' answers rating their level of knowledge of the practices to the their responses to our item asking the participants to explain the practices, we revealed alignment between their rated knowledge of the NGSS practices, as both the coded answers and self-report answers were reflective of low levels of knowledge. However, we found a moderate misalignment between the coded answers to the free-response knowledge of the CCSS-Math practices item (about 80% minimal or less levels of understanding) and the selected-response knowledge of the CCSS-Math practices levels of knowledge (moderate level of understanding). Our correlation analysis between the responses to the CCSS-M knowledge selected-response and coded free-response items was $r$=.42 ($p$<.01). We found a similar value for the NGSS knowledge selected-response and free-response items, $r$=.49 ($p$<.01). While the correlations were significant, there is still about 82% unexplained variance for the CCSS-M knowledge and 76% unexplained variance for the NGSS knowledge, which suggests that the participants may be over-confident in the knowledge levels of the standards.

The teachers held relatively positive perceptions (on a 5 point Likert Scale) that STEM practices would significantly increase their students' learning with the NGSS having a mean of 3.56 (SD = .94) and the CCSS-Math having an average of 3.92 (SD = .80). However, our results suggest that although the teachers held relatively positive perceptions of the learning potential of the STEM practices, they also had very limited knowledge of how to create opportunities to engage their students in the practices, tended not to communicate the practices to their students, and had very constrained knowledge of how to assess their students learning of the practices.

**Confidence and Process used in Implementing STEM Practices**

Our second research question asked, "What are K-12 teachers' confidence in their abilities and the processes used to implement core STEM practices learning opportunities as part of their curriculum?" Our analysis revealed that the participants were low to moderate in their confidence (on a 10 point Likert like scale) in their abilities to integrate the NGSS practices (M = 3.19, SD = 2.37) and the CCSS-Math practices (M = 4.81, SD = 2.09) into their teaching. We found a similar trend in the participants' responses to our item asking them to share their attention toward the practices in their teaching (based on a 10 point Likert like-scale) with a moderate level of attention associated with the CCSS-M practices (M = 5.29, SD = 2.41) and relatively low level of attention to the NGSS practices (M = 2.54, SD = 1.99). Again, we found that the teachers were more confident and attentive to the CCSS-Math practices than the NGSS science and engineering practices.

**Learning and Teaching STEM Practices**

Our third research question asked, "Are K-12 teachers discussing STEM practices in their schools and are they expected to teach the practices?" To answer this question, we examined the responses to our items associated with professional conversations related to the STEM practices and expectations for teaching the practices. The teachers' responses to these items suggest that there is not much support for the practices in the schools. When asked to respond (on a 5 point Likert scale) to the item asking how much the core STEM practices were discussed in faculty meetings, our participants indicated that the NGSS practices were rarely discussed (M = 1.34, SD = .69) and the CCSS-Math practices were discussed somewhat (M = 2.56, SD = 1.02). Similarly, answers to our item asking the teachers to share the expectations for teaching the STEM practices (on a 10 point Likert-like scale) indicated low expectations for both the CCSS-Math practices (M = 3.10, SD = 2.37) and NGSS practices (M = 2.45, SD = 2.06). Thus, our results indicate very limited conversation and low expectations for the implementation of the both the CCSS-M and NGSS practice standards.

**Influence of Professional Development**

Our fourth research question asked, "What influence did attending the i-STEM professional development summer institute have on participating K-12 teachers' knowledge and perceptions of core STEM practices?" To answer this question, we conducted a paired samples t-test to compare the participants' pre and post-institute responses. We conducted our first set of tests on our selected response items associated with perceptions of the STEM practices. Our analysis revealed significant increases in all our measures of perceptions. The largest gains were split between the shifts in the teachers' perceptions of the CCSS-Math practices and the NGSS practices (see Table 2). Our results suggest that the teachers' were influenced by the professional development which led them to shift their professional perceptions of the STEM practices.

Table 2. *Comparison of Perceptions of STEM Practices Pre and Post Institute*

| Comparison | | M | SD | SEM | t-stat | Sig. (p) |
|---|---|---|---|---|---|---|
| Confidence in effectively integrating the CCSS-Math (10 pt scale) | Pre | 4.81 | 2.09 | .11 | 12.76** | <.000 |
| | Post | 6.23 | 2.00 | .10 | | |
| Confidence in effectively integrating the NGSS (10 pt scale) | Pre | 3.21 | 2.37 | .13 | 18.32** | <.000 |
| | Post | 5.56 | 2.31 | .12 | | |
| Knowledge of CCSS-Math practices (10 pt scale) | Pre | 5.67 | 2.21 | .11 | 10.63** | <.000 |
| | Post | 6.63 | 1.86 | .10 | | |
| Knowledge of the NGSS practices (10 pt scale) | Pre | 2.62 | 2.00 | .10 | 20.46** | <.000 |
| | Post | 5.04 | 2.03 | .10 | | |
| Rate the level to which you think you currently attend to the CCSS-Math practices (10 pt scale) | Pre | 5.31 | 2.40 | .13 | 10.50** | <.000 |
| | Post | 6.30 | 2.19 | .11 | | |
| Rate the level to which you think you currently attend to the NGSS practices. (10 pt scale) | Pre | 3.92 | .80 | .04 | 3.01** | <.003 |
| | Post | 4.06 | .78 | .04 | | |
| The CCSS-Math practices would increase students learning (5 pt scale) | Pre | 2.54 | 1.99 | .11 | 17.62** | <.000 |
| | Post | 4.62 | 2.24 | .12 | | |
| The NGSS practices would increase students learning (5 pt scale) | Pre | 3.56 | .93 | .05 | 9.09** | <.000 |
| | Post | 4.09 | .75 | .04 | | |

*** Significant at .01*

We continued our analysis of data pre and post to determine influence of the professional development by examining the coded responses to our free-response knowledge and teaching questions (see Table 3). With one exception, we found significant increases in the knowledge of the practice communicated by the teachers from pre to post institute. The exception was the comparison of the teachers responses to the items related to how they could create opportunities to engage their students in math practices, an item in which we did not find a significant change. Unlike the perception items, all of the greatest gains were related to the NGSS science and engineering practices. Again, the results suggest that the PD summer institute increased the participants' knowledge for how to structure instruction and curriculum to foster student development of STEM core practice knowledge.

Table 3. *Comparison of Coded Knowledge and Teaching of STEM Practices Pre and Post Institute*

| Coded Response Item | TEST | M | SD | t-test | Sig. (p) |
|---|---|---|---|---|---|
| Define the CCSS-M Practices | Pre | 1.94 | .654 | 3.72** | <.001 |
| | Post | 2.10 | .606 | | |
| List the CCSS-M Practices | Pre | 2.03 | .832 | 3.81** | <.001 |
| | Post | 2.27 | .902 | | |
| Assess Student Learning of the CCSS-M Practices | Pre | 1.97 | .728 | 2.09** | <.001 |
| | Post | 2.06 | .664 | | |
| Communicate the CCSS-M Practices to Students | Pre | 2.02 | .826 | 2.07** | <.001 |
| | Post | 2.12 | .806 | | |
| Create Opportunities to Engage Students in the CCSS-M Practices | Pre | 2.16 | .726 | -1.66 | <.05 |
| | Post | 2.09 | .741 | | |
| Define the NGSS Practices | Pre | 1.42 | .679 | 9.29** | <.001 |
| | Post | 1.91 | .643 | | |
| List the NGSS Practices | Pre | 1.22 | .777 | 9.32** | <.001 |
| | Post | 1.84 | .814 | | |
| Assess Student Learning of the NGSS Practices | Pre | 1.26 | .882 | 7.67** | <.001 |
| | Post | 1.72 | .712 | | |
| Communicate the NGSS Practices to Students | Pre | 1.33 | .950 | 6.20** | <.001 |
| | Post | 1.75 | .799 | | |
| Create Opportunities to Engage Students in the NGSS Practices | Pre | 1.45 | 1.008 | 6.33** | <.001 |
| | Post | 1.89 | .774 | | |

** *Significant at .01*

## Discussion and Implications

Core STEM practices are critical to the development and professional success of engineers and STEM professional. As the core STEM practices become recognized as part of the K-12 STEM curriculum, there is a need to determine how teachers perceive the practices, their levels of knowledge of the practices, and how they are teaching the practices. There is also need for effective professional development to enhance K-12 educator knowledge of and engagement with teaching core STEM practices.

In answering our first research question we found that the participants had very limited knowledge of core STEM practices, but knew more about the CCSS-Math practices than the NSGG science and engineering practices. We attribute the difference in knowledge to the focus on mathematics in K-12 education to a much greater extent than science and engineering, particularly at the K-8 grade levels. We also recognize that the focus on STEM practices is a rather recent development in K-12 education and therefore K-12 educators are unlikely to have experienced the practices as part of their education. The implications of constrained teacher knowledge of STEM practices is their very limited implementation of and focus on STEM practices in K-12 STEM education. The lack of attention toward STEM practices in K-12 education may stifle the development of student knowledge and understanding of the work of engineers and impact the potential interest and pursuit of becoming an engineer or STEM professional.

The analysis for our second research question revealed low to moderate levels of confidence and attention in teaching to core STEM practices. Similar to the knowledge of the CCSS-Math and NGSS practices, we posit that the lack of explicit attention to STEM practices in teacher preparation and professional development has constrained opportunities for knowledge development and the corresponding confidence and subsequent attention to the practices in teaching and learning. Thus, we speculate that teachers will need substantial support to help them develop confidence for teaching the practices and developing the skills and knowledge that will lead them to increased attention to effective standards implementation in their instruction and curriculum choices. If the increases in teacher confidence and attention in the STEM practices do take place, K-12 students may learn more about the practices of engineering and will be more likely to consider education and careers in engineering.

In answering our third research question, we revealed that STEM practices are not typically part of the educational conversation in schools and there is low to moderate expectations for teaching the core STEM practices. We speculate that the limited knowledge and experience with core STEM practices has constrained teacher appreciation for the importance of attending to the practices and has diminish the value of conversations in schools associated with STEM practices. Thus, we maintain that there is a need to adjust the culture and emphasis in schools and the priorities of K-12 educators to bring the attention and emphasis in schools necessary to effectively address core STEM practices. We contend that if teachers do not engage in conversations about STEM practices and/or are not expected to teach STEM practices, the quality and quantity of individuals in the next generation of STEM professionals will not increase, and the ability to meet the demand for qualified engineers will continue to be a struggle.

The outcome of the analysis of our final research question revealed our i-STEM professional development program that explicitly addressed core STEM practices increased an array of participating K-12 educators' perceptions, attitudes, knowledge and ideas for implementation of core STEM practices. We postulate that our professional development was effective because of the explicit attention to the practices, our modeling of the practices, and the multiple opportunities for the educators to engage in discussions and applications of STEM practices. Implications for the effectiveness of our professional development program is the potential for scaling the process to provide greater influence and increased K-12 teacher STEM practices knowledge, perceptions, attitudes and implementation of curriculum and instruction that results in conditions that increase student engagement in core STEM practices.

## Limitations

The first limitation is the nature of our data, which was self-report. While self-reported data has been established as effective for gathering data[28] the reporting process may not effectively illuminate the complexity of teachers' thoughts and instruction associated with the STEM practices. Thus, observing teachers teaching their students may reveal additional insight into how they are addressing STEM practices in their instruction. Given the rather low levels on some of the responses to our item, we suspect that our participants were honest in their replies and did not over-inflate or miss-calibrate most of their responses. More school and classroom level observations and interviews with teachers may provide the data needed to determine the accuracy of our data. Gathering additional data in schools and teachers through observation of teaching and examination of artifacts of student learning associated with STEM practices is an excellent direction for future research.

The second limitation of our research is the limited geographic area from which the participants were drawn. Although we had over 500 K-12 teachers who were dispersed across Idaho, their STEM practices associated perceptions and processes could have been heavily influenced by state policy and priorities, which may limit the scope of our research. Conducting a similar survey in states with varied levels of attention to core STEM practices as part of their policies would provide a greater portrayal of the current state of teacher knowledge, perceptions and implementation of core STEM practices. Thus, replicating our research in different locations is an excellent direction for future research.

The third limitation of our research is the pre-experimental method we used to determine impact of our professional development. Of course, a random control trial would be required to determine cause and effect. However, we have also gathered data on our project for over 5 years and continue to amass a wide range of data that indicate significant influence on professional development and changes in the practices of the participating K-12 teachers. We are currently delayed post-testing our participants to determine the long term influence on their perceptions, beliefs and engagement with core STEM practices.

## Conclusion

There is general agreement that there is a need to address STEM education in K-12 education as part of the solution to increasing the number of students pursuing STEM careers, particularly in high demand areas such as engineering. As a potential catalyst for increasing K-12 student interest and pursuit of STEM professions, several groups of stakeholders have developed new K-12 STEM education learning standards, which are composed of a combination of content and practice standards. While the content standards are not considered a radical deviation from previous STEM content standards, the practice standards are a new element that provides the motivation and framework for aligning K-12 STEM education with the STEM activities that take place out of school, particularly the activities of STEM professionals. Given the major shift from traditional approaches to STEM teaching, many K-12 educators are in need of core STEM practice focused professional development. We designed and implemented i-STEM - a week-long core STEM practice professional development summer institute, and found that our approach had significant influence on the core STEM practices knowledge, perceptions, ideas and engagement of the participating K-12 educators. Our research and intervention addressed the need to increase K-12 teacher capacity to positively contribute to the preparation students to be STEM professionals, and is another solution to assuring the quality and quantity of the next generation of STEM professionals.

## References

[1] Holdren, J. P., Lander, E. S., & Varmus, H. (2010). *Prepare and inspire: K-12 education in science, technology, engineering, and math (STEM) for America's future.* (Executive Report). Washington, D.C.: President's Council of Advisors on Science and Technology

[2] Carnevale, A. P., Smith, N., & Melton, M. (2011). STEM: Science Technology Engineering Mathematics. Retrieved from. http://cew.georgetown.edu/STEM/

[3] National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). *Common core state standards for mathematics*. Washington DC: National Governors Association Center for Best Practices, Council of Chief State School Officers,.

[4] National Research Council. (2011). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC:National Academies Press.

[5] Kumar, M. (2013). New K–12 science education standards may face implementation challenges. *Eos, Transactions American Geophysical Union*, *94*(18), 166-167.

[6] Stage, E. K., Asturias, H., Cheuk, T., Daro, P. A., & Hampton, S. B. (2013). Opportunities and challenges in next generation standards. *Science*, *340*(6130), 276-277.

[7] Talanquer, V., & Sevian, H. (2013). Chemistry in past and new science frameworks and standards: gains, losses, and missed opportunities. *Journal of Chemical Education*, *91*(1), 24-29.

[8] Wysession, M. E., Colson, M., Duschl, R. A., Lopez, R. E., Messina, P., & Speranza, P. (2013, December). Challenges of the NGSS for Future Geoscience Education. In *AGU Fall Meeting Abstracts* (Vol. 1, p. 0645).

[9] Best, J., & Cohen, C. (2013). The Common Core: are state implementation plans enough? *Mid-continent Research for Education and Learning (McREL)*.

[10] Pedersen, S., Arslanyilmaz, A., & Williams, D. (2009). Teachers’ assessment-related local adaptations of a problem-based learning module. *Educational Technology Research and Development*, *57*, 229–249.

[11] NGSS Lead States. (2013). *Next generation science standards: For states, by state*s. Washington, DC: The National Academies Press.

[12] Barakos, L., Lujan, V., Strang, C. (2012). *Science, technology, engineering, mathematics (STEM): Catalyzing change amid the confusion*. Portsmouth, NH: RMC Research Corporation, Center on Instruction.

[13] Nadelson, L. S., Fuller, M., Briggs, P., Hammons, D., Bubak, K., & Sass, M. (2012). The tension between teacher accountability and flexibility: The paradox of standards-based reform. *Teacher Education and Practice*, *25*(2), 196-220.

[14] Nadelson, L. S., Pluska, H., Moorcroft, S. Jeffery, A. & Woodard, S. (2014). Educators perceptions and knowledge of the common core state standards. *Issues in Teacher Education*, *23*(2), 47-66.

[15] Lieberman, J. (2009). Reinventing teacher professional norms and identities: The role of lesson study and learning communities. *Professional development in education*, *35*(1), 83-99.

[16] Geijsel, F., Sleegers, P., van den Berg, R., & Kelchtermans, G. (2001). Conditions fostering the implementation of large-scale innovation programs in schools: Teachers’ perspectives. *Educational Administration Quarterly*, *37*(1), 130-166.

[17] National Science Board. (2014). *Science and engineering indicators 2014*. Arlington VA: National Science Foundation (NSB 14-01).

[18] Banilower, E. R., Smith, P. S., Weiss, I. R., Malzahn, K. A., Campbell, K. M., & Weis, A. M. (2013). *Report of the 2012 National Survey of Science and Mathematics Education*. Chapel Hill, NC: Horizon Research, Inc.

[19] Deemer, S. (2004). Classroom goal orientation in high school classrooms: Revealing links between teacher beliefs and classroom environments. *Educational Research*, *46*(1), 73-90.

[20] Meece, J. L., Anderman, E. M., & Anderman, L. H. (2006). Classroom goal structure, student motivation, and academic achievement. *Annu. Rev. Psychol.*, *57*, 487-503.

[21] Stipek, D. J., Givvin, K. B., Salmon, J. M., & MacGyvers, V. L. (2001). Teachers' beliefs and practices related to mathematics instruction. *Teaching and teacher education*, *17*(2), 213-226.

[22] Turner, J. C., Meyer, D. K., Midgley, C., & Patrick, H. (2003). Teacher discourse and sixth graders' reported affect and achievement behaviors in two high-mastery/high-performance mathematics classrooms. *The Elementary School Journal*, 357-382.

[23] Lynch, S., Kuipers, J., Pyke, C., & Szesze, M. (2005). Examining the effects of a highly rated science curriculum unit on diverse students: Results from a planning grant. *Journal of Research in Science Teaching*, *42*(8), 912-946.

[24] Nadelson, L. S., Callahan, J., Pyke, P., Hay, A., Dance, M., & Pfiester, J. (2013). Teacher STEM perception and preparation: Inquiry-based STEM professional development for elementary teachers. *The Journal of Educational Research*, *106*(2), 157-168.

[25] Nadelson, L. S. and Seifert, A. (2013). Perceptions, engagement, and practices of teachers seeking professional development in place-based integrated STEM. *Teacher Education & Practice*, *26*(2), 242.

[26] Beaudoin, C. R., Johnston, P. C., Jones, L. B., & Waggett, R. J. (2013). University support of secondary stem teachers through professional development. *Education*, *133*(3), 330-339.

[27] Creswell, J. (2003). *Research design: Qualitative, quantitative and mixed methods approaches (2nd ed.)*. Thousand Oaks, CA: SAGE Publications.

[28] Chan, D. (2009). So why ask me? Are self report data really that bad? In C. E. Lance and R. J. Vandenberg (Eds.), *Statistical and methodological myths and urban legends: Doctrine, verity and fable in the organizational and social sciences* (pp309-335). New York, NY: Routledge.

Appendix

## Core STEM Practices - i-STEM 2014

***Please consider the Common Core State Standards - MATH (Idaho Core) when answering the following.***

1. In my school, faculty are expected to integrate the Common Core State Standards - Math practices into their instruction.

| Not at all | Somewhat | Continuously |
|---|---|---|

2. Rate your level of knowledge of the practices of the Common Core State Standards – Math.

| No Knowledge | Some Knowledge | Expert Knowledge |
|---|---|---|

3. In your own words define the "practices" of the CCSS- math.

4. List as many of the CCSS-math practices that you can recall and provide a brief description of each practice.

5. Rate the level to which you think you currently attend to the CCSS-Math practices.

| Not at all | Somewhat | Continuously |
|---|---|---|

6. How do you assess your students' development of CCSS-Math practices?

7. What opportunities do you create to engage your students in the CCSS-Math practices?

8. How do you communicate the CCSS-Math practices to your students?

9. Rate the confidence in your ability to effectively integrate the CCSS - Math practices with the science content you teach.

| No Confidence | Some Confidence | Extremely Confident |
|---|---|---|

10. We discuss the CCSS-Math practices in faculty meetings.

- Never
- Seldom
- Sometimes
- Frequently
- Continuously

11. The CCSS-Math practices would significantly increase my students learning of mathematics.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

***Please consider the Next Generation Science Standards (NGSS) when answering the following.***

12. In my school, faculty are expected to integrate the NGSS practices into their instruction.

| Not at all | Somewhat | Continuously |
|---|---|---|

13. Rate your level of knowledge of the practices of the Next Generation Science Standards

| No Knowledge | Some Knowledge | Expert Knowledge |
|---|---|---|

14. In your own words define the practices of the Next Generation Science Standards.

15. List as many of the Next Generation Science Standards practices that you can recall and provide a brief description of each practice.

16. Rate the level to which you think you currently attend to the NGSS practices.

| Not at all | Somewhat | Continuously |
|---|---|---|

17. How do you assess your students' development of NGSS practices?

18. What opportunities do you create to engage your students in the NGSS practices?

19. How do you communicate the NGSS practices to your students?

20. Rate the confidence in your ability to effectively integrate the NGSS practices with the science content you teach.

| No Confidence | Some Confidence | Extremely Confident |
|---|---|---|

21. We discuss the NGSS practices in faculty meetings.

- Never
- Seldom
- Sometimes
- Frequently
- Continuously

22. The NGSS practices would significantly increase my students learning of science and engineering.

- Strongly Disagree
- Disagree
- Neutral

- Agree
- Strongly Agree