Wanted For 21st Century Schools: Renaissance STEM Teacher Preferred

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Abstract

As education seeks to mold itself to fit the demands of the 21st century, STEM education will continue to be an important consideration. The integrated and crosscutting nature of STEM is incorporated into the *Next Generation Science Standards* in which engineering design is raised to the same level as scientific inquiry and is expected to be taught in science classrooms. This report analyzes a 2014 Utah survey of science teachers to understand how prepared Utah science teachers are to teach engineering design and the relationship between their preparedness and beliefs about whether building prototypes, computer modeling, and mathematical modeling belong in the instruction of engineering design. Ordinary least squares (OLS) regression results indicate that physics teachers are the most prepared to teach engineering design and that science teachers are significantly more prepared to teach an integrated STEM curriculum, such as engineering design, when they agree that modeling techniques from each STEM discipline should be used in instruction. It is recommended that teachers in STEM classrooms be comfortable and fluid in each STEM discipline, instead of representing one single subject expertise with some familiarity with the other three.

Keywords: STEM, Next Generation Science Standards, engineering design

Each year that passes brings us deeper into the 21st century. A long list of skills necessary to succeed in upcoming years has been suggested that includes practical ingenuity, creativity, communication, business and management, leadership, high ethical standards, professionalism, dynamism, agility, resilience, flexibility, lifelong learners, critical thinking, problem solving, collaboration, innovation, digital literacy, initiative, accountability, productivity, responsibility, and self-direction (National Academy of Engineering [NAE], 2004; Trilling & Fadel, 2009). These skills are “not new,” but they need new attention in curricula (Rotherham & Willingham, 2010).

One venue for addressing the integration of 21st century skills and content is through science, technology, engineering, and mathematics (STEM) education. STEM is inherently interdisciplinary (Asghar, Ellington, Rice, Johnson, & Prime, 2012), and its disciplines have been described as “‘vital for a thriving economy’” (Margaret A. Honey; as cited in National Academies of Sciences, Engineering, and Medicine, 2014, para. 2). One effort to deliver

STEM in an integrated format is found in the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013).

Citing a need for educational standards to be updated to reflect the most current educational research, the final draft of the NGSS was released in 2013 (Next Generation Science Standards [NGSS], 2017a). Prior to their publication, 40 states expressed interest in the standards (Branch, 2013), and all 26 states that were involved in the development process made commitments to “give serious consideration to adopting the resulting” standards (NGSS, 2017b, para. 1). As of 2016, 18 states and Washington, DC have voted to fully adopt the NGSS (Heitin, 2016). As a landmark publication, its influence is likely to be felt to some degree in almost all states, even if outright adoption does not occur.

As the effect of the NGSS reverberates throughout much of the country, one might ask if STEM education will become more prominent. One change in this regard is that engineering design, a problem-solving process used by engineers, has received increased weight and importance. In fact, “science and engineering are integrated into science education by raising engineering design to the same level as scientific inquiry in science classroom instruction at all levels and by emphasizing the core ideas of engineering design and technology applications” (NGSS Lead States, 2013, p. xiii).

The elevation and pronounced infusion of engineering into science standards appear to be in line with recommendations from the National Academy of Engineering (NAE) that encourage such infusions of engineering into other content areas (National Academy of Engineering, Committee on Standards for K–12 Engineering Education, 2010). Such infusion has already begun to happen in other STEM fields—most notably among technology teachers, who have largely adopted engineering. The adaptation from technology teachers into technology and engineering teachers is reflected in the title of the professional organization known today as the International Technology and Engineering Education Association (ITEEA). In 2010, the organization changed its name to properly position the association regarding “its increased role in delivering the ‘T’ & ‘E’” in the strong STEM education movement that was occurring (International Technology and Engineering Education Association, 2012, para. 2).

The NAE has noted technology and engineering education’s dedication to engineering-related content; however, they have also noted that technology and engineering education does not have the critical mass of 380,000 that they estimate are necessary to deliver engineering content to the entire country (National Academy of Engineering, Committee on Standards for K–12 Engineering Education, 2010). Hence, integrating engineering content into STEM fields with more teachers (i.e., science) appears to be a logical move.

Although the decision to integrate and give extra emphasis to engineering has been met with applause in many corners, it has also met with some concern about the readiness of science teachers to deliver deft STEM instruction. Using survey data from approximately 5,000 science teachers randomly sampled in discipline strata from 2,000 randomly sampled schools around the country, Banilower et al. (2013) reported that a mere 7% of high school science teachers felt that they were "very well prepared to teach" engineering (p. 26). This number should garner attention because "well prepared teachers produce higher student achievement" (National Council for Accreditation of Teacher Education, 2006, p. 3). Indeed, "the expertise of educators is a key factor—some would say *the* key factor—" in delivering STEM education well (NAE, 2014, p. 3).

The November 2013 issue of the *National Science Teacher Association Report* included a commentary from science education faculty members at Vanderbilt University who expressed their opinion about the state of preparedness of science teachers to teach engineering: "With the release of the Next Generation Science Standards (NGSS), it is clear engineering education will need to play a more prominent role in K–12 science classrooms. This creates a dilemma, as a second missing 'E' is all too often in engineering education: 'expertise.'" (Johnson & Cotterman, 2013, p. 3). Further, the National Academy of Sciences, Engineering, and Medicine (Wilson, Schweingruber, & Nielsen, 2015) has concluded that many teachers lack substantial experience with the engineering content laid out in the NGSS.

In this study, we use data from a 2014 survey of Utah science teachers to understand factors that contribute to a STEM teacher's preparedness or lack thereof to integrate STEM content from disciplines that are not native to them. Specifically, this question will be addressed in two steps. First, science teachers' feelings of preparedness for cutting across STEM content areas to address a subject such as engineering will be measured to determine if the sample reflects the low levels of preparedness found nationally. Second, science teachers' levels of preparedness will be examined for any potential relationship that they may have with teachers' opinions about appropriateness in cutting across all STEM disciplines to solve engineering (i.e., nonnative subject STEM) problems, which are referred to here as *modeling solutions*.

Research Design

Participants

Because science is sometimes thought to be the main discipline in STEM, we chose to survey a sample of science teachers. The survey used was administered through Utah's e-mail database of science teachers. At the time of data collection, Utah did not have a comprehensive list of science teacher e-mail addresses; however, the state did maintain a list of science teachers who voluntarily opted in to receive communications from state science leaders. In the 2013–2014 school year during which data were collected, approximately 650 of Utah's 1,517 science teachers were on the e-mail list that the state maintained. These teachers received the survey in an e-mail, and a follow-up e-mail was sent out to encourage further responses. All e-mails were sent through the office of

Sarah Young, the Utah state science coordinator. Participation was voluntary, and no incentives for participation were given.

Instrument

Because the NGSS were largely based on the *Framework for K–12 Science Education* (the Framework; National Research Council [NRC], 2012), the survey instrument was developed using the language found in the Framework to best reflect the definition and elements of engineering design as they are represented in the NGSS. The survey instrument contained 15 items, 11 items that were intended to capture a teacher's feelings of preparedness to engage with engineering design and four items that were intended to capture a composite score reflecting a teacher's likelihood to model solutions in various ways.

The 11 items relating to preparedness included statements about engineering design asking teachers to indicate how prepared they felt in each of the areas. A response key was provided next to each level of preparedness in order to unify interpretations of the various levels of preparedness (see Appendix).

The four items relating to modeling solutions included statements that cut across different types of modeling solutions. Because engineering design problems do not have "correct" answers (NRC, 2012), it is necessary to evaluate solutions on some other criteria. To this end, the teachers were asked to what extent they agreed that different types of solution modeling should be used in the instruction of engineering design in their classroom. These included mathematical modeling, computer modeling, scientific modeling, and construction or building of a prototype.

For accuracy in the distinctions between engineering and science, the 11 statements regarding preparedness and the four statements regarding statistical modeling were adapted directly from the Framework (NRC, 2012), which is also the document that provided the foundation for the NGSS.

The eight practices of science and engineering that the *Framework* identified as essential for all students to learn, and describes in detail, 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. (NGSS Lead States, 2013, p. 48)

Both disciplines, science and engineering, use all eight of these practices—albeit in slightly different ways. To accurately capture science teachers' feelings of preparedness about the engineering-specific use of these practices, and implementation of differing styles of solution modeling, the language of the survey closely paralleled that of the section in the Framework entitled "Distinguishing Practices in Science From Those in Engineering" (pp. 50–54) wherein a side-by-side comparison of science and engineering applications is presented. An excerpt from this section of the Framework is shown in Figure 1. The items on the survey instrument were either adapted or taken directly from this section of the Framework.

Distinguishing Practices in Science from Those in Engineering	
1. Asking Questions and Defining Problems	
Science begins with a question about a phenomenon, such as "Why is the sky blue?" or "What causes cancer?," and seeks to develop theories that can provide explanatory answers to such questions. A basic practice of the scientist is formulating empirically answerable questions about phenomena, establishing what is already known, and determining what questions have yet to be satisfactorily answered.	**Engineering** begins with a problem, need, or desire that suggests an engineering problem that needs to be solved. A societal problem such as reducing the nation's dependence on fossil fuels may engender a variety of engineering problems, such as designing more efficient transportation systems, or alternative power generation devices such as improved solar cells. Engineers ask questions to define the engineering problem, determine criteria for a successful solution, and identify constraints.

Figure 1. Excerpt from the *Framework for K–12 Science Education* showing a side-by-side comparison of science and engineering applications (NRC, 2012, p. 50).

To ensure a clear distinction between science and engineering and accurate representation of the various STEM modeling techniques, the instrument was also reviewed by a committee of STEM experts. A pilot group of high school teachers was consulted to ensure that the instrument's language was not too dense or difficult to understand.

Data

The data were collected in May 2014, which is important for two reasons. First, the school year was drawing to a close in Utah, and the timing likely affected the response rate, which was only 14%. Second, the data were drawn from a population of teachers whose state standards had not yet been affected by the NGSS in any way. At that time, the standards had been published for less than a year, and the state had not yet placed any expectations on teachers to follow them; it was also unlikely that teachers had received any professional development on implementing the NGSS. Thus, the participating science teachers had not been given any express engineering standards, expectations, or training regarding the NGSS—a window of opportunity that was likely closing. The data, therefore, can be interpreted as a snapshot in time of one STEM discipline's readiness to adopt a more integrated STEM curriculum—after the standards had been published and before any professional development was administered.

The data were analyzed using ordinary least squares (OLS) regression. OLS regression is robust to violations of the normality assumption when sample sizes are sufficiently large, which is true for these data. Robust standard errors were used in all calculations to account for any heteroscedasticity present in the data.

Results

The 11 survey items (α = 0.96) measuring feelings of preparedness to engage with engineering design indicated an average preparedness between *somewhat prepared* and *prepared* ($M = 3.45$, $SD = 0.97$). The four survey items (α = 0.84) measuring teachers' agreement with the use of different modeling solutions in instruction has a mean response just above *agree* ($M = 4.15$, $SD = 0.54$). This means that on the whole, science teachers agreed that modeling techniques from all STEM disciplines should be used when teaching engineering design.

Table 1
Summary of Regression Analysis on Secondary Science Teachers' Self-Reported Preparedness to Teach Engineering Design

	Model 1		Model 2	
Variable	β	*SE*	β	*SE*
Intercept	3.18^{***}	(0.25)	3.32^{***}	(0.23)
Number of years teaching	-0.01	(0.01)	-0.01	(0.01)
Biology endorsement	-0.07	(0.30)	-0.14	(0.30)
Physics endorsement	1.19^{***}	(0.29)	0.87^{**}	(0.32)
Physical science endorsement	0.35	(0.23)	0.36	(0.21)
Earth science endorsement	0.45	(0.29)	0.35	(0.27)
Chemistry endorsement	-0.04	(0.30)	-0.03	(0.31)

Environmental science endorsement	-0.15	(0.35)	-0.11	(0.34)
Integrated science endorsement	0.02	(0.27)	-0.03	(0.26)
Other science endorsement	0.11	(0.26)	-0.02	(0.24)
Modeling solutions			0.45^{*}	(0.19)
Observations	75		74	
R^2	0.27		0.33	
Adjusted R^2	0.17		0.22	
Residual *SE*	0.87 (*df* = 65)		0.83 (*df* = 63)	
F Statistic	2.69^{**} (*df* = 9; 65)		3.11^{***} (*df* = 10; 63)	

Note. The dependent or outcome variable is measured on a 5-point, 11-item (α = 0.96) Likert scale in which 5 = *very well prepared*, 4 = *prepared*, 3 = s*omewhat prepared*, 2 = *not very prepared*, 1 = n*ot prepared at all*. Output was created using the *R* statistical package developed by Hlavac (2015).
$^{*}p < 0.1$. $^{**}p < 0.05$. $^{***}p < 0.01$.

The data were collected from a group of licensed science teachers with varying endorsements in Utah. Therefore, Model 1 in Table 1 takes for its reference category a licensed teacher who is interested in teaching science, has no science endorsements, and has 0 years of teaching experience (e.g., a recent graduate). Model 1 in Table 1 has an intercept value of 3.18, indicating that such a teacher, on average, would feel slightly above *somewhat prepared*. If the new science teacher has a physics endorsement then he or she would, on average, report a 4.37 feeling of preparedness to interact with engineering practices. This rating would place the new physics teacher as being somewhere between *prepared* and *very well prepared*.

None of the other science teaching endorsements were statistically significant, nor was time spent teaching statistically significant. The physics coefficient is not only large in magnitude, but is also much larger than its standard error, leading to a high degree of statistical significance. This suggests that something about the preparation of physics teachers leads them to feel more prepared to teach engineering design than other science teachers.

When examining the teachers' agreement that modeling techniques from all STEM disciplines should be used when teaching engineering design, the impact of holding a physics endorsement is lessened, and most of the other nonsignificant coefficients are also reduced—as seen in Model 2 of Table 1. The intercept stays in approximately the same place, rising only slightly. The model's adjusted *R* squared is 0.22, reflecting an increase of .05, indicating that

5% more variance in the observed data can be explained by a person's agreement that modeling techniques from all STEM disciplines should be used when teaching engineering design. The effect of a physics endorsement is also lower. A one unit increase in modeling solutions represents an increase of 1 point a person's overall score on the four modeling solutions items (e.g., an average shift across all indicators from *somewhat prepared* to *prepared*). A one unit increase in modeling solutions can also be thought of as an increase of approximately two standard deviations.

In interpreting the data, an important consideration is that the data for modeling solutions have been centered at its mean (corresponding approximately with *likely* to use modeling). Therefore, if a person is average in their views about interdisciplinary STEM instruction, no increase in preparedness is predicted. A person's baseline preparedness, as indicated by the intercept, can go up or down depending on whether the teacher is above or below average in their likelihood to model solutions.

A teacher with a physics endorsement, who *strongly agrees* that one should use various STEM modeling techniques to create and test solutions—from mathematics all the way to construction—would have a predicted composite score of 4.64 on the preparedness to teach engineering survey items and would be categorized as closer to *very well prepared* than *prepared*.

Discussion

In interpreting the results of this study, one should be mindful of the cross-sectional nature of the dataset, which does not allow for causal inferences. Further, the convenience sample and low response rate likely introduce bias. More data should be collected in ways that do not have the same limitations to check for replication of the findings. As with many electronic surveys, the participants are left to their own internalized meaning for each number on the Likert scale. Although an attempt to unify understanding was made by providing participants with examples to clarify the meaning of each possible response, there is likely some variation among respondents in their interpretation of the scale, which damages the internal validity of the study.

The four survey items measuring a teacher's agreement regarding modeling solutions account for multiple methods of modeling, including: computer modeling, mathematical modeling, scientific modeling, and real-life construction and building models or prototypes. Embedded in these varying methods of modeling are the skillsets for each letter of the STEM acronym. A teacher who is strong in only one area is unlikely to have a composite score as high as a teacher who is strong in each area. Given the sample of science teachers, it is likely that an average score in the sample captured here reflects strong scientific prowess and that an above average score indicates additional skills in some combination of mathematics, technology, and engineering.

The finding that physics teachers in this sample felt more prepared to teach engineering design than other science teachers is interesting. The increased feelings of preparedness could be due to the location of the study; in Utah, Physics with Technology is offered as a secondary course, giving physics teachers more exposure to other STEM disciplines. It could also be due to the related nature of physics and engineering. There are undoubtedly traits about people that drive them to choose specific endorsements and careers. These same underlying and unknowable traits may contribute to the physics teachers' preparedness to engage with engineering content. Although we have suggested some possible reasons here, we do not know enough to make any causal judgements about why the physics teachers in this study felt more prepared to teach engineering design than other science teachers. This finding warrants further investigation.

The NGSS's inclusion of engineering design is a move toward a more integrated STEM curriculum. These data suggest that individuals who are comfortable in all of the fields—science, technology, engineering, and mathematics—are the most prepared to teach the integrated curriculum. As we move toward a more integrated curriculum and as STEM continues as a cornerstone of that movement, it will be important to provide all teachers involved with STEM opportunities to better learn each area with an emphasis on areas of personal weaknesses.

We recommend that future studies evaluate how well-rounded STEM teachers affect student outcomes in STEM courses, as compared to single-subject teachers (e.g., math teacher, science teacher, technology teacher) without additional training teaching STEM courses.

Conclusion

With the inclusion of STEM across the standards, it becomes clear that educators in the STEM disciplines must work together and break down personal silos in order to break down curricular silos. The message for administrators is to look to teachers from all STEM-related fields when selecting a teacher for STEM courses. When staffing STEM classrooms, math teachers and technology and engineering teachers should be considered along with science teachers. Furthermore, even the most well-rounded STEM teachers should be provided with professional development in the areas in which they are not certified.

Preservice instructors in science, technology, engineering, and mathematics should consider ways to incorporate more STEM preparation into teacher preparation. Policy makers and stakeholders should also realize that STEM is more than simply science and sometimes mathematics. STEM is a concept that breaks through silos and rewards those who are willing to blend content from multiple subjects. A teacher's willingness to go beyond scientific or mathematical modeling of solutions and engage with computer modeling as well as physical creation through the construction and building of prototypes is predictive of higher preparedness in teachers.

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Appendix

Table A1
Possible Responses on the 11 Survey Items Regarding Preparedness to Teach Engineering Design and Their Corresponding Description

Response	Evaluated statement	Assigned value
Very well prepared	I have taught it before and feel prepared to teach it again.	5
Prepared	I know enough to teach it, but have never prepared a lesson with it.	4
Somewhat prepared	I know about it, but would need to brush up on it.	3
Not very prepared	I have seen it and know what preparation materials to consult, but I do not know much else about it.	2
Not prepared at all	I have never seen it before.	1