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Perceived Barriers And Solutions: Engineering Design Implementation

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PERCEIVED BARRIERS AND SOLUTIONS: ENGINEERING DESIGN IMPLEMENTATION

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Dedicated to all my past and future students, all my past and future teachers.

Learning is not something that can be done to you or for you.

Thank you for joining me on this adventure.

NLU Digital Commons Document Origination Statement

This document was created as *one* part of the three-part dissertation requirement of the National Louis University (NLU) Educational Leadership (EDL) Doctoral Program. The National Louis Educational Leadership EdD is a professional practice degree program (Shulman et al., 2006).

For the dissertation requirement, doctoral candidates are required to plan, research, and implement three major projects, one each year, within their school or district with a focus on professional practice. The three projects are:

- Program Evaluation
- Change Leadership Plan
- Policy Advocacy Document

For the **Program Evaluation** candidates are required to identify and evaluate a program or practice within their school or district. The "program" can be a current initiative; a grant project; a common practice; or a movement. Focused on utilization, the evaluation can be formative, summative, or developmental (Patton, 2008). The candidate must demonstrate how the evaluation directly relates to student learning.

In the **Change Leadership Plan** candidates develop a plan that considers organizational possibilities for renewal. The plan for organizational change may be at the building or district level. It must be related to an area in need of improvement, and have a clear target in mind. The candidate must be able to identify noticeable and feasible differences that should exist as a result of the change plan (Wagner et al., 2006).

In the **Policy Advocacy Document** candidates develop and advocate for a policy at the local, state or national level using reflective practice and research as a means for supporting and promoting reforms in education. Policy advocacy dissertations use critical theory to address moral and ethical issues of policy formation and administrative decision making (i.e., what ought to be). The purpose is to develop reflective, humane and social critics, moral leaders, and competent professionals, guided by a critical practical rational model (Browder, 1995).

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Abstract

Engineering Design, part of the practices dimension of the Next Generation Science Standards, NGSS, is widely recognized as the most challenging piece for teachers to implement. It involves practices that teachers are unfamiliar with, have not taught before, have not been taught, and have not experienced as a student. This manuscript documents a mixed-methods survey of over 200 K-12 teachers on their perceptions of both the greatest barriers to implementation of Engineering Design, and those items that will be of most value as a solution to those barriers. A systems approach to understanding Engineering Design was utilized; with data collection in the change arenas of Competencies, Conditions, Culture, and Context.

Preface: Leadership Lessons

While analyzing the results for the case study project evaluation portion of the dissertation, I became aware of faculties' perceived needs for support in implementing Engineering Design. (Engineering Design is the part of the Next Generation Science Standards, NGSS, that most researchers have determined will be the most difficult to implement.) Thus, I determined to probe teachers' perceptions of barriers and solutions to Engineering Design implementation. Also, it seemed important to me to do a study that would broaden the focus of my Engineering Design research beyond one school. So I prepared a descriptive study that would look at many different districts, different sizes, different levels, and different levels of experience on the part of the teachers across two states.

This experience allowed me to work with many different schools across the Midwest. In the end, over 200 teachers responded to my survey. They represented every grade level and every level of experience. I learned lessons in communication – as I was often making a "cold call", opening a conversation with no prior relationship. Finding common ground, establishing a working relationship, opening lines of communication were very important.

I also learned valuable lessons in leadership at the district level. My descriptive study used a systems approach to education, comparing results from competencies, conditions, culture, and context. This approach is fundamental to understanding education communities, as most complex systems cannot be reduced to a simple single cause, single effect model.

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Section I: Introduction

In the fall of 2013, I began a case study, a formative assessment of faculty preparedness to teach Engineering Design. Engineering Design is a part of the Practices dimension of the Next Generation Science Standards, NGSS (NGSS, 2013). During the interview portion of that study, I asked faculty members their perceptions of barriers and solutions to implementation of Engineering Design. Those interviews led to this further descriptive study on Engineering Design Implementation.

Rationale

There is an urgent need for a better curriculum in K-12 science education due to the current lack of high achieving high school graduates, the need for students to be competitive in the global job market, and the need for technologically and scientifically advanced personnel who can continue or increase the technological advances of the United States. In the book, The Global Achievement Gap, Tony Wagner describes the growing gap between what even our best schools are teaching and the skills all students will need (2010). The job market, although currently strengthening, has produced many jobs, but most have low wages. Many of the jobs that produce the highest salaries are those in the science and engineering fields. Our schools should prepare students for the advanced skills that those careers require. Finally, a scientifically literate society is important to our country because,

> Science is also at the heart of the United States' ability to continue to innovate, lead, and create the jobs of the future. All students-whether they become

technicians in a hospital, workers in a high tech manufacturing facility, or Ph.D. researchers- must have a solid K-12 science education" (NGSS, 2013).

The NGSS has three major dimensions: (a) Practices, (b) Cross-cutting Concepts, and (c) Disciplinary Core Ideas (NGSS, 2013). These dimensions and their associated components are important and interrelated. However, it is the Engineering Design component of the Practices dimension that is arguably the most challenging component for teachers and school districts, because it is the only one that introduces entirely new instructional practices into the standards-based curriculum, even though the practices are rooted in Technological Design (Padilla & Cooper, 2012). Science and technology have such an intertwined relationship that to teach one without the other does a disservice to both (Beven & Raudebaugh, 2004). Students will learn more, retain more, and be more motivated through active participation in Engineering Design (Heroux, Turner & Pellegrini, 2010). Students who are taught processes of Engineering Design become more intrinsically motivated in the science classroom (Coryn, Pellegrini, Evergreen, Heroux, & Turner, 2011). This component is largely absent from most college science education programs (Lederman & Lederman, 2013). There are still no national requirements for teaching Engineering Design to pre-service science teachers or elementary teachers (Brownstein et al., 2009; Hagevik et al., 2010). Thus, science teachers and elementary teachers are being asked to teach what they have never been taught.

Research Questions

The research questions for this study are:

1. What are the barriers to implementation of Engineering Design as perceived by K-12 teachers?

2. What is the relative importance of those barriers?

3. What factors do teachers see as solutions to the barriers in implementing Engineering Design?

4. What is the relative importance of those solutions?

Goals

The goals of this study are:

- To answer the above questions in order to inform teachers, administrators, and stakeholders for fruitful discussions on Engineering Design Implementation, and
- To provide insight for an advocacy plan for Engineering Design Implementation.

Demographics

Faculty from many schools were chosen from districts in the midwest. Schools were chosen whose administrators were interested in the study and the implementation of NGSS and Engineering Design. Schools were chosen based on their voluntary agreement after their solicitation in October and November of 2014. All settings are described with anonymity. The science faculty (at high schools and middle schools) or faculty that are associated with implementation of NGSS (at elementary schools) were asked to voluntarily respond to a survey.

About 32% of the respondents were male, 68% female. About 34% of the respondents teach in the elementary levels, almost 19% teach 7th or 8th grade, and about 47% teach high school. The respondents have a wide range of experience. 10% have been involved in K-12 education for five years or less, 21.3% have been involved in K-12 educaton twenty-five years or more. Figure 1 on the next page sumarizes this data.

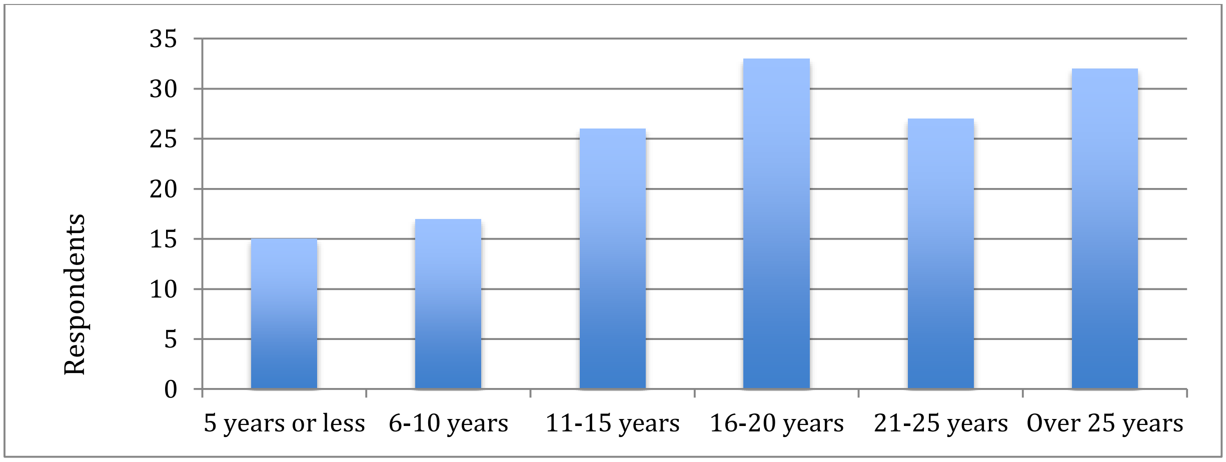

Figure 1 Years of experience in K-12 education of the respondents

The experience level of the respondents in their present building is somewhat less than their overall experience, as illustrated in Figure 2 below. This indicates that the respondents have some mobility and have less experience in their present building than their total experience.

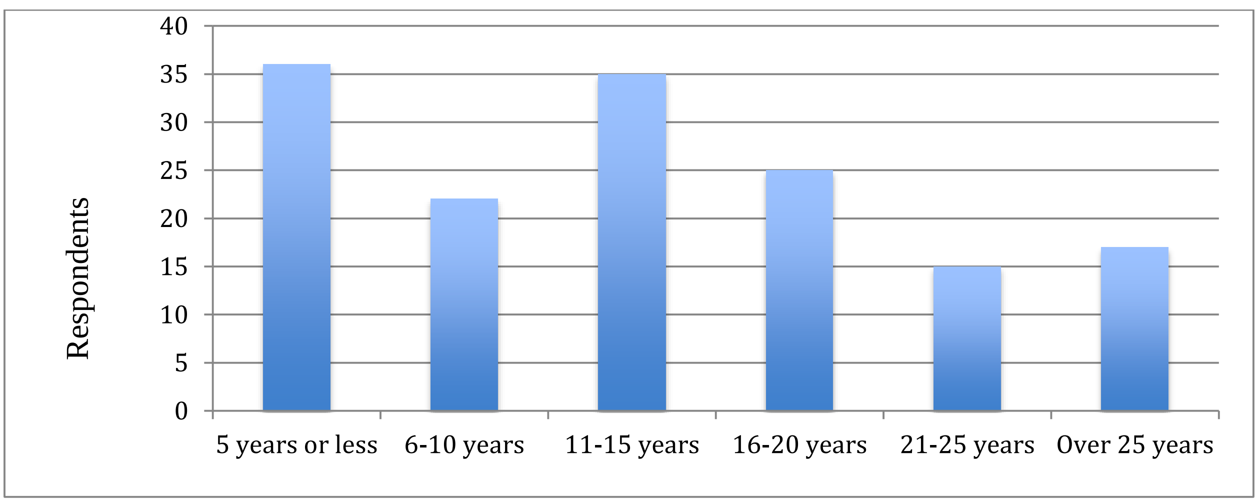

Figure 2 Years of experience in the present building of the respondents

Section II: Assessing the System, As - Is

This paper is focused on formulation of a change plan – implementation of NGSS and Engineering Design - and will begin with an analysis of the way things are right now, "As – Is", and move to a vision of the way things ought to become, "To – Be". The proposed methodology for this change, relevant literature, and strategies and actions for the proposed change will also be presented.

In both the current analysis and the future vision, a systems approach will guide the organization of this paper and the research, focusing on the four constructs taken from *Change Leadership: A Practical Guide to Transforming Our Schools* by Wagner et al. (2006): Competencies, Conditions, Culture, and Context. A systems approach is required because it is widely recognized that educational organizations are complex – there is much more going on than simple cause and effect. In *The Practice of Adaptive Leadership: Tools and Tactics for Changing Your Organization and the World* (2009), Heifetz et al. address the need for a systems approach, advocating for diagnosing the system before determination of a course of action (Heifetz, Grashow, & Linsky). Similarly, *Visible Learning: A Synthesis of Over 800 Meta-Analyses Relating to Achievement* by John Hattie (2009), is organized into chapters that focus on contributions from: the student, the home, the school, the teacher, the curricula, and the teaching approach. These and other studies require we consider many facets to any problem we hope to address. A systems approach is a framework for addressing the components of a learning organization (Senge, 1990).

In this systems analytical framework, the current competencies, conditions, culture, and context will be discussed with the goal of Engineering Design implementation. The evaluation of each of these constructs is based on the previous case study (Turner, 2015).

Analysis of Now

Figure 3, below, illustrates the four key components four analyzing educational systems using Wagner's (2006) framework: competencies, conditions, culture, and context.

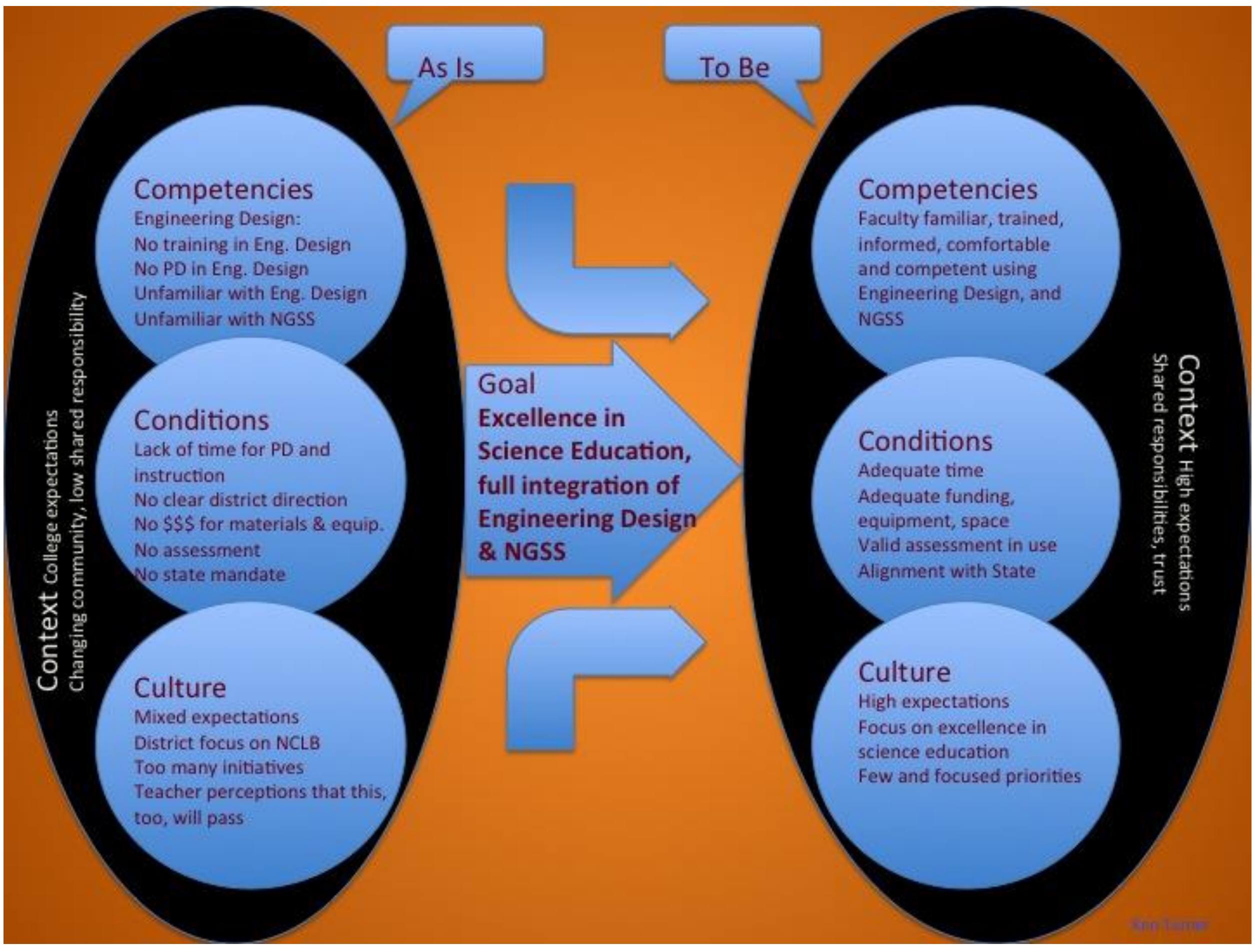

Figure 3 Analysis of the key components in educational systems change. The key components in a systems approach may be categorized as competencies, conditions, culture, and context (Wagner et al., 2006); the current state of the system is on the left

and the vision for the future is on the right. The goal of the change, central to both the "as is" and the "to be" is at the center of the figure.

Competencies

The repertoire of skills and knowledge of teachers and administrators is the change arena of competencies (Wagner et al., 2006). In the case study by Turner, teachers at Central High School – a fictitious name for a real high school in the Midwest – have had almost no training or professional development in Engineering Design, and they have had few discussions on implementation of Engineering Design. Most have read few or no scholarly articles on Engineering Design and they consider themselves to be unfamiliar with Engineering Design and the Next Generation Science Standards (Turner, 2015).

Conditions

The real constraints of time, space, and resources as they affect student learning make up the change arena of conditions (Wagner et al., 2006). The teachers at Central High School noted lack of time (in the school day and in the school year), lack of professional development, lack of funding for materials and equipment, lack of space, and the lack of an assessment as being barriers to implementation of Engineering Design and the NGSS (Turner, 2015). The fact that the state has not yet accepted NGSS is a foundational barrier.

Culture

Those shared values, beliefs, expectations, and behaviors related to students, teachers, administrators, and their roles and relationships in the building, district, and community are all part of the change arena of culture (Wagner et al., 2006). There are mixed expectations at Central High School (Turner, 2015). The pressures associated with the federal legislation of No Child Left Behind, NCLB, continue to be the greatest factor in determining any professional development in most districts (Justin, 2004). Most teachers at Central High feel that the district spends too much time and resources on the high stakes testing that is part of NCLB. Teachers feel over-burdened by the many initiatives that are underway. Many teachers express a fear that their work towards implementation of Engineering Design and NGSS will become just one more initiative that will be abandoned in a few years (Turner, 2015).

Context

The social, historical, and economic realities that impact the students, citizens, and community served by the schools constitute the change arena of context (Wagner et al., 2006). The community of Central High School has expectations of college readiness. The school serves a community that is increasing in diversity and in families that need economic support. There is little shared responsibility for education in the community beyond that of paying taxes (Turner, 2015).

Summary

This description of present conditions is preliminary. As noted by Wagner et al., "… simple linear cause-and-effect explanations sometimes miss the fact that today's effect may in turn be tomorrow's cause, influencing some other part of the system" (page 98, 2006). In further study, greater clarity within the change arenas of competencies, conditions, culture, and context will emerge. Considering the present conditions and envisioning the future is an important beginning. It is this beginning that can shape the process of getting from the place where we are to the place we want to be. That process is the goal of change leadership.

Section 10: Research Methodology

Research Design

A survey was developed as the principle data-collection tool to assess the implementation of NGSS and Engineering Design at the schools. The survey was given to the science teachers (middle school and high school level) or teachers (elementary level) that are involved (or will become involved) with implementation of NGSS and Engineering Design. The survey was designed to gather information in each of the four arenas for change - competencies, conditions, culture, and context – that are delineated in the systems approach of Wagner et al. (2006), as well as update the information gathered in the previous survey (Turner, 2015). The survey instrument has a strong quantitative perspective in most questions with a Likert scale indicating the relative measure of importance of each item (Appendix A). There are some open-ended questions that will entail a qualitative analysis. Thus, the survey instrument and the design of the study is that of mixed methods.

In Bryman’s (2006) typology for choosing mixed methods, the following reasons apply: greater validity may result from the combined results and mutual corroboration, completeness will increase by using both methods to evaluate the study, increases in credibility due to the parallel construction will result, and instrument development may occur. Instrument development is based on the premise that the survey items used in this study may be further modified for future studies. The faculty survey, though based on previous research, has never been trialed before. There will be modification for more comprehensive wording for the likely future use as a template for similar and further studies.

Participants

Anonymous schools chosen for the study are those schools in the Midwest that responded positively to my solicitation. They are in many different districts. The leadership at each school voluntarily agreed to take part in this research project. From each school, teachers involved in science instruction or implementation of NGSS volunteered to take the survey.

Data Collection Technique

The survey was crafted based on both the previous work on Engineering Design (Turner, 2015) and based on the systems approach of Wagner et al. (2006). That survey instrument was modified for an online format, due to the choice of several of the participating districts. (See Appendix A.) The survey could only be accessed through the code provided by the author. Safeguards to protect the anonymity of the participants were also provided. There were several facets covered in the survey.

The first six items were designed to gauge the participant's familiarity with Engineering Design, with questions how often the respondent had read articles or attended a conference on Engineering Design. They are also asked to rank their familiarity with Engineering Design.

In the next section, on capacity, there were several questions on capacity that asked questions on the extent of certain factors inhibiting their ability to implement Engineering Design. There were questions on professional development, reading literature, college course work, and other items related to building capacity.

In the section of conditions respondents were to choose the extent to which working conditions inhibit their ability to implement Engineering Design. There were questions on time allotted for planning, space in the classroom, need for supplies, and other questions related to conditions.

Following the section on conditions was a section on culture. Respondents were to choose the extent to which culture/collegiality inhibit their ability to implement Engineering Design. There were questions on building climate, district priorities, and teacher evaluation focus.

The next section of the survey was a section on context. Respondents were to choose the extent to which context inhibit their ability to implement Engineering Design. There were questions on parental support, school and community trust, concerns of community members, and other items related to context.

Additionally, respondents were asked to envision their school pursuing full implementation of Engineering Design. They were asked how valuable certain actions would be toward that goal. Survey items included items like re-prioritization of district goals, state acceptance of NGSS, re-prioritization of resource allocation to support Engineering Design and others.

Finally, there were questions on the respondents' gender, the grade level they taught, their experience in teaching, and their experience in their present building. This information appears as an earlier portion of the paper on the respondents.

The survey was used to collect data from the end of October to the end of December of 2014. The survey was then closed and data was downloaded for analysis.

Data Analysis

The downloaded survey results were placed onto several spreadsheets and survey number, mean, and standard deviation was calculated. The responses to each of the open-ended questions were copied and pasted into a table, then categories were chosen and tabulated for those responses.

Limitations to the Study

The number of respondents was over 200, and the schools represented large and small districts. However, the data from this study was not nationally representative nor was the return rate above 80%. As such, this study cannot be considered to be representative of the nation or the states where the study was conducted. It can only be considered a descriptive study, confirming the data from the earlier case study (Turner,2015), and laying the groundwork for a nationally representative survey.

There are several types of education research studies according to the book *Scientific Research in Education* (NRC, 2002). Descriptive studies are those that present information on the way things are; answering the question, what is happening now? A causative study presents information on systemic effects; answering the question, does X cause Y Both types of questions are common in scientific education research, but the Descriptive studies always come before the Causative studies. My study is a descriptive study; it is preliminary because the survey, although grounded on the work done by Coryn et al. and the case study by Turner (2015), has never been trialed before.

Additionally, I admit as chief researcher, my total support for the implementation of Engineering Design at all levels. This may have led to a bias in either my collection methods or analysis. However, I have presented all of my data and the basis for my conclusions to ensure transparency in the study for later research.

Section IV: Relevant Literature

The literature review section of this study will be focused on those relevant areas of Engineering Design and Educational Change.

Engineering Design

The statements and citations in this section are important additions to the equally important Engineering Design segment of the Literature Review from the Program Evaluation. The current section is meant to augment - not supplant - that offered previously in the Program Evaluation.

The importance of Engineering Design is introduced in the following excerpt from Steve Metz (2014), editor of *The Science Teacher*, published by the National Science Teacher Association, in a special edition devoted to Engineering Design.

> By incorporating engineering design and technology, we allow students to apply their developing science understanding to solving problems that are practical, relevant, and important in their daily lives. Students develop important critical-thinking and problem-solving skills as they work through engineering design challenges. Such activities can help spark student interest and encourage students who belong to groups historically underrepresented in science and engineering fields (p.6).

This reflection on Engineering Design resonates well with the Seven Survival Skills espoused by Wagner in his book, *The Global Achievement Gap: Why Even Our Best Schools Don't Teach the New Survival Skills Our Children Need – And What We Can Do About It* (2010). Heroux (2012) sums up many of the student benefits of Engineering Design this way, "It does provide a forum within which a real world approach to science can flourish; where real problems can be tackled, and where failure becomes a positive learning experience, as in the real world. It makes science relevant" (p. 92). With its emphasis on critical thinking, problem solving, analysis, creativity, collaboration, and communication; Engineering Design seems ideally suited to play a dramatic role in improving education. The international recognition of the necessities of scientific literacy is noted by Server and Guven (2014), "The need for individuals literate in science and technology who will carry their societies into contemporary civilization has been understood by the international education community" (p. 1601). Some of the many benefits to incorporation of Engineering Design include: increasing student interest in STEM (Science, Technology, Engineering, and Mathematics) fields (Wheeler, Whitworth, & Gonczi, 2014), increases in engagement and creativity (Gilbert & Wade, 2014), better science curriculums (Razzouk, Dyehouse, Santone, & Carr, 2014); as well as demonstration of science concepts and engineering practices (Boesdorfer & Greenhalgh, 2014).

Engineering Design leads to increasing student engagement in their own learning; "they have engaged in authentic scientific inquiry and technological design" (Turner, 2010). Teachers use Engineering Design because of its ability to engage and motivate students (Heroux, 2012). A statement on the goals of many science teachers may be taken from an article on Engineering Design by Heroux, Turner, and Pellegrini 2010), "When science is taught with a real world, hands-on, student-centered, cutting edge focus; students respond in ways you may never have thought possible" (p. 231).

Engineering Design is envisioned as a practice through which science content may be taught. Engineering Design is intertwined with but not the same as scientific inquiry (Heroux, Turner, & Pellegrini, 2010). Engineering Design, a component of the Practices dimension of the NGSS, is also known as technological design. Engineering Design includes: defining and delimiting engineering problems, designing solutions to engineering problems, and optimizing the design solution (NGSS, 2013)**.** Clarifying the relationship of scientific inquiry and Engineering Design, NGSS states that, "For example, scientific inquiry involves the formulation of a question that can be answered through investigation, while Engineering Design involves the formulation of a problem that can be solved through design" (NGSS, Appendix J, 2013). Some of the key provisions of Engineering Design include that there is more than one solution, that students will test and improve their solutions iteratively, that students will develop the mindset of "fail early and solve", and that its use will help to build the skills of creativity and collaboration for the students.

The unique challenges of Engineering Design revolve around the core dilemma that teachers are being asked to teach something they have not been taught; additionally, they have not been taught science through the practice of Engineering Design (Padilla & Cooper, 2012; Lederman & Lederman, 2013; Turner, 2015). As teachers tend to teach the way they have been taught, this is especially problematic (Padilla & Cooper, 2012; Cooper, 2013; Hoffman & Turner, 2015). At its most fundamental level, Engineering Design within the NGSS necessitates a change in the way science is taught, K-20 (Cooper, 2013). In part, Cooper states:

> That is, if we teach our introductory chemistry courses in a traditional way, using lectures, cookbook laboratories, and multiple-choice testing, future teachers will not develop expertise in asking questions, developing models, or arguing from

evidence. It is important for those of us who teach these courses to reflect on the impact we may have on future teachers, and frankly on future scientists and engineers (p. 679).

Thus, NGSS requires creation and/or adaptation of every part of the science curriculum including such disparate parts as supplies, assessments, and the priorities of time for each unit. This will require support for the existing teachers as well as pre-service teachers (Cooper, 2013). It also means there will need to be changes in the methods used by college teachers of chemistry, biology, physics, geology, etc. Essentially, there is *no* area of science instruction that is *not* affected by NGSS, and the greatest challenge is in the practice of Engineering Design.

Educational Change

The educational community is rocked by one call for reform after another – and no wonder. The changing priorities from diverse populations often pull in different directions. Technology is transforming society, and educational organizations must also be changed. Our perspective must be one of learner-centeredness, including instruction and assessment (Aslan & Reigeluth, 2013).

Wagner et al. (2006) point out the fact that our current educational system is not designed to meet the needs of today's students, or tomorrow's students (Wagner et al., 2006). A simple cause and effect model for educational systems does not exist. Diverse populations, changing moral norms, acceptance of violence, accelerating technology and communication, widening gaps in income disparity, and demands for accountability have served to make education systems a chaotic and turbulent arena (Brown & Moffett, 1999). This turbulent arena can seem overwhelming at times, but opportunities for growth and improvement abound. As Wheatley notes (2006), "Disorder can be a source of order… and growth is found in disequilibrium, not in balance" (p. 20).

There is disequilibrium. There are opportunities for improvement. But how do we find those areas for improvement. Hattie (2009) notes the difficulties in a published synthesis of syntheses related to increasing student achievement.

> Everything seems to work in the improvement of student achievement. There are so many solutions and most have some form of evidence for their continuation. Teachers can thus find support to justify almost all of their actions – even though the variability about what works is enormous (p. 6).

Choosing the path for school improvement is the work of change leadership, but how is that path chosen? Westover (2014) suggests that a strategic focus be defined, followed by an analysis of the system for those interventions that will have the greatest impact. Collins (2005) stated a similar need to seek an analysis and calibration of the goal before attempting a change. Boyatzis and McKee (2005)would add that it is just as important for the leader to be mindful of their inward selves as it is to analyze the system that requires an improvement. These authors would be joined by Collinson, Cook, and Conley (2006) who additionally caution that almost any effort at change inevitably results in tensions and dilemmas. Improving an educational system is an adaptive challenge, it cannot be solved by plugging some new location into an old formula. "What we have then is a new challenge – one for which there exists no adequate knowledge base on which school leaders can draw. Nor will there ever be a 'base' that can be applied routinely to all situations" (Wagner et al., 2006, p. 10).

An adaptive challenge can only be addressed by changing people's priorities, beliefs, habits, and loyalties. It will require new perspectives built on the best of the past with collaboration and innovation. Diagnosis of the system – including the challenge, the organization, and the politics - is the first step. This step must occur before any interpretation or intervention should be attempted (Heifetz et al., 2009).

Thus, it is widely understood that educational change is a dynamic and adaptive challenge, and a thorough analysis of the system should be undertaken before an intervention is planned. Wagner et al. (2006) have presented an organizational scheme to aid in that analysis. They suggest visualizing an educational organization as an entity whose elements aggregate because of their interrelated purposes and action, the systems approach. Thus, understanding the integration of the parts of the system is an important first step of improving education. Understanding the interrelated parts of Engineering Design Implementation is the framework for this paper.

Section V: Data Analysis and Interpretation

Over 200 respondents chose to submit surveys. These results were tabulated and organized to gather anonymous information on familiarity with Engineering Design and perceptions of barriers to its implementation and foreseen solutions; broken into the four C's; competencies, conditions, culture, and contexts. Results in regard to competencies, conditions, culture, and contexts will be presented, each in turn. This will be followed by an analysis of the results.

Survey Findings

Competencies. In the survey, questions 7 – 11 dealt with teacher capacity. Every one of these questions had a mean score of a little over 3 (3.11 – 3.43) when respondents could choose from 1 = no extent, this factor does not inhibit my ability to implement Engineering Design; 5 = to a great extent, this factor greatly inhibits my ability to implement Engineering Design. The range of those reporting "no extent" was from 15.8% to 18.7%. The participants who reported that a particular factor "greatly inhibits" ranged from 25.2% to 31.6%, or always greater than the percentage choosing "no extent". Questions eight and eleven received responses that indicated these were the greatest factors inhibiting Engineering Design Implementation from the Competencies section, they were the questions dealing with professional development and experience with Engineering Design. These results are summarized in Table 1 on the next page.

Capacity: To what extent, if any, do the following inhibit your ability to implement Engineering Design activities in your classroom, right now?
1= no extent, this factor does not inhibit my ability to implement Engineering Design;
5= to a great extent, this factor greatly inhibits my ability to implement Engineering Design

Question	1= no extent	2	3	4	5= great extent	Mean	SD
7. My familiarity with Engineering Design. (n=171)	30 17.5%	35 20.5%	28 16.4%	35 20.5%	43 25.2%	3.15	1.46
8. My professional development focused on Engineering Design. (n=171)	32 18.7%	27 15.8%	22 12.9%	37 21.6%	53 31.0%	3.30	1.51
9. My reading of literature on Engineering Design. (n=171)	31 18.1%	34 19.9%	35 20.5%	28 16.4%	43 25.2%	3.11	1.45
10. My lack of college coursework focused on Engineering Design. (n=171)	28 16.4%	22 12.9%	32 18.7%	38 22.2%	51 29.8%	3.36	1.45
11. My experience level with Engineering Design. (n=171)	27 15.8%	25 14.6%	21 12.3%	44 25.7%	54 31.6%	3.43	1.46

Table 1 Results from the Competencies section of the Engineering Design Implementation survey

When the data is disaggregated into male or female groups, or into groups based on the level the respondents teach (Elementary, Middle School, or High School) the differences in the Capacities arena is not very great. It is interesting to note that elementary teachers perceived their lack of familiarity with Engineering Design as a greater barrier to implementing Engineering Design than did their high school teacher counter parts. Similarly, they perceived their lack of professional development as a greater barrier. Results are summarized in Table 2 on the next page.

Capacity: To what extent, if any, do the following inhibit your ability to implement Engineering Design activities in your classroom, right now?
1= no extent, this factor does not inhibit my ability to implement Engineering Design;
5= to a great extent, this factor greatly inhibits my ability to implement Engineering Design.

Quesstion	Male	Female	Elem	MS	HS	Universal Mean
7. My familiarity with Engineering Design. (n=171)	2.98	3.17	3.46	3.17	2.86	3.15
8. My professional development focused on Engineering Design. (n=171)	3.24	3.26	3.44	3.03	3.21	3.30
9. My reading of literature on Engineering Design. (n=171)	3.10	3.03	3.12	3.07	3.01	3.11
10. My lack of college coursework focused on Engineering Design. (n=171)	3.26	3.33	3.36	3.52	3.19	3.36
11. My experience level with Engineering Design. (n=171)	3.40	3.43	3.62	3.66	3.21	3.43

Table 2 Mean value for various groups of respondents (Male, Female, Elementary teachers, Middle School teachers, and High School teachers) in the Competencies arena

Conditions. Questions 12-24 of the survey dealt with items from the Conditions arena of change. Respondents were asked to what extent these conditions items inhibited their ability to implement Engineering Design; from 1 = no extent, this factor does not inhibit my ability to implement Engineering Design; 5 = to a great extent, this factor greatly inhibits my ability to implement Engineering Design. The mean scores were from 2.33 for not enough days in the school year to 4.00 for not enough time for planning in the school day. Items chosen by more than half the respondents as a four or five, five greatly inhibiting the teacher’s ability to implement Engineering Design, included not enough time for planning in the school day (72.7%), not enough time for meeting with teacher teams (64.6%), lack of Engineering Design assessments (62.1%), lack of Engineering Design activities for the course (58.8%), need for more equipment (51.9%), need for more supplies ((51.9%), and student prior experiences with Engineering Design were insufficient (50.3%). Results from the Conditions section of the survey are summarized in Table 3 on the next page.

Conditions: To what extent, if any, do the following inhibit your ability to implement Engineering Design activities in your classroom, right now?
1= no extent, this factor does not inhibit my ability to implement Engineering Design;
5= to a great extent, this factor greatly inhibits my ability to implement Engineering Design

Question	1= No Extent	2	3	4	5 great extent	Mean	SD
12. Not enough time allotted for planning in the school day. (n=161)	8 5.0%	15 9.3%	21 13.0%	42 26.1%	75 46.6%	4.00	1.19
13. Not enough time allotted for meeting with teacher teams. (n=161)	14 8.7%	18 11.2%	25 15.5%	40 24.8%	64 39.8%	3.76	1.33
14. Not enough time allotted for science class in the school day. (n=159)	30 18.9	33 20.8%	32 20.1%	28 17.6%	36 22.6%	3.04	1.43
15. Not enough days allotted for school in the school year. (n=160)	59 36.9%	37 23.1%	31 19.4%	18 11.3%	15 9.4%	2.33	1.34
16. Space in my classroom is insufficient. (n=160)	49 30.6%	32 20.0%	42 26.3%	25 15.6%	12 7.5%	2.49	1.28
17. Need for more equipment (one time purchase). (n=160)	19 11.9%	34 21.3%	24 15.0%	41 25.6%	42 26.3%	3.33	1.38
18. Need for more supplies (every year purchase). (n=160)	13 8.1%	41 25.6%	23 14.4%	42 26.3%	41 25.6%	3.36	1.34
19. Class size is too large. (n=161)	34 21.1%	40 24.8%	28 17.4%	39 24.2%	20 12.4%	2.82	1.35
20. Lack of Engineering Design assessments in my course. (n=160)	14 8.8%	22 13.8%	26 16.3%	53 33.1%	45 28.1%	3.58	1.28
21. Lack of Engineering Design activities for my course. (n=160)	16 10.0%	21 13.1%	29 18.1%	44 27.5%	50 31.3%	3.57	1.33
22. Student abilities in math are too low. (n=161)	28 17.4%	44 27.3%	51 31.7%	24 14.9%	14 8.7%	2.70	1.18
23. Student abilities in reading are too low. (n=161)	27 16.8%	42 26.1%	56 34.8%	25 15.5%	11 6.8%	2.70	1.13
24. Student prior experience in Engineering Design are insufficient. (n=161)	16 9.9%	31 19.3%	33 20.5%	40 24.8%	41 25.5%	3.37	1.32

Table 3 Data collected from the Engineering Design Implementation Survey focusing on the Conditions arena

When the data is disaggregated into male or female groups, or into groups based on the level the respondents teach (Elementary, Middle School, or High School) the differences in the Conditions arena is not very great. Although the differences are not great, the middle school respondents noted time for meeting with teacher groups a larger barrier to implementing Engineering Design than the other groups. At the same time, they also noted that time for planning was also a barrier, as did the high school teachers. Elementary teachers noted that time allotted for science in the school day as a greater barrier than their high school teacher counterparts did. This compares with informal interviews with the author, as many elementary teachers note that their time for science instruction has been given to math or literacy instruction. Results are summarized in Table 4 on the next page.

Conditions: To what extent, if any, do the following inhibit your ability to implement Engineering Design activities in your classroom, right now?
1= no extent, this factor does not inhibit my ability to implement Engineering Design;
5= to a great extent, this factor greatly inhibits my ability to implement Engineering Design

Question	Male	Female	Elem	MS	HS	Universal Mean
12. Not enough time allotted for planning in the school day. (n=161)	4.10	3.95	3.86	4.10	4.11	4.00
13. Not enough time allotted for meeting with teacher teams. (n=161)	3.66	3.75	3.60	4.07	3.71	3.76
14. Not enough time allotted for science class in the school day. (n=159)	2.98	2.99	3.40	3.07	2.69	3.04
15. Not enough days allotted for school in the school year. (n=160)	2.37	2.24	2.30	2.41	2.23	2.33
16. Space in my classroom is insufficient. (n=160)	2.32	2.47	2.80	2.52	2.14	2.49
17. Need for more equipment (one time purchase). (n=160)	3.18	3.30	3.43	3.45	3.10	3.33
18. Need for more supplies (every year purchase). (n=160)	3.22	3.31	3.45	3.55	3.08	3.36
19. Class size is too large. (n=161)	2.70	2.83	2.80	3.21	2.65	2.82
20. Lack of Engineering Design assessments in my course. (n=160)	3.48	3.58	3.76	3.69	3.36	3.58
21. Lack of Engineering Design activities for my course. (n=160)	3.52	3.54	3.70	3.48	3.44	3.57
22. Student abilities in math are too low. (n=161)	2.72	2.70	2.48	2.79	2.83	2.70
23. Student abilities in reading are too low. (n=161)	2.70	2.69	2.62	2.72	2.74	2.70
24. Student prior experience in Engineering Design are insufficient. (n=161)	3.32	3.33	3.56	3.17	3.24	3.37

Table 4 Mean value for various groups of respondents (Male, Female, Elementary teachers, Middle School teachers, and High School teachers) in the Conditions arena.

Culture. Questions 25-30 of the survey dealt with items from the Culture arena of change. Respondents were asked to what extent these items inhibited their ability to implement Engineering Design; from 1 = no extent, this factor does not inhibit my ability to implement Engineering Design; 5 = to a great extent, this factor greatly inhibits my ability to implement Engineering Design. The range of mean scores on these factors was from 1.52 to 3.01. In general, respondents did not feel as strongly that Culture items were inhibiting their ability to implement Engineering Design. Of the items from the Culture section, the current district priorities was the greatest factor inhibiting Engineering Design implementation, with 40.2% of respondents choosing a four or a five. Results from the Culture section of the survey are summarized in Table 5 on the next page.

Culture: To what extent, if any, do the following inhibit your ability to implement Engineering Design activities in your classroom, right now?
1= no extent, this factor does not inhibit my ability to implement Engineering Design;
5= to a great extent, this factor greatly inhibits my ability to implement Engineering Design

Question	1=	2 No Extent	3	4	5=	Mean great extent	SD
25. Lack of trust with colleagues. (n=159)	105	34	15	2	3	1.52	0.86
	66.0%	21.4%	9.4%	1.3%	1.9%		
26. Lack of trust with building administration. (n=159)	83	40	16	10	10	1.89	1.19
	52.2%	25.2%	10.1%	6.3%	6.3%		
27. Building climate. (n=159)	63	42	22	17	15	2.24	1.32
	39.6%	26.4%	13.8%	10.7%	9.4%		
28. Current district priorities. (n=159)	38	23	34	28	36	3.01	1.47
	23/9%	14.5%	21.4%	17.6%	22.6%		
29. Current building priorities. (n=159)	38	29	34	23	35	2.92	1.47
	23.9%	18.2%	21.4%	14.5%	22.0%		
30. Teacher evaluation focus. (n=158)	43	18	36	28	33	2.94	1.49
	27.2%	11.4%	22.8%	17.7%	20.9%		

Table 5 Data from the Engineering Design Implementation Survey focusing on the Culture arena

When the data is disaggregated into male or female groups, or into groups based on the level the respondents teach (Elementary, Middle School, or High School) the differences in the Culture arena are not very great. In the culture arena, the respondents chose all items as being lower in terms of the extent to which it is a factor that inhibits their ability to implement Engineering Design. Of these factors, current district priorities ranked the highest among all groups for the factor inhibiting their ability to implement Engineering Design. Table 6 on the next page summarizes these results.

Culture: To what extent, if any, do the following inhibit your ability to implement Engineering Design activities in your classroom, right now?
1= no extent, this factor does not inhibit my ability to implement Engineering Design;
5= to a great extent, this factor greatly inhibits my ability to implement Engineering Design

Question	Male	Female	Elem	MS	HS	Universal Mean
25. Lack of trust with colleagues. (n=159)	1.44	1.51	1.60	1.45	1.43	1.52
26. Lack of trust with building administration. (n=159)	1.92	1.81	1.74	1.83	1.93	1.89
27. Building climate. (n=159)	2.10	2.25	2.26	2.10	2.22	2.24
28. Current district priorities. (n=159)	2.74	3.11	2.96	3.03	3.03	3.01
29. Current building priorities. (n=159)	2.64	3.00	2.96	2.69	2.94	2.92
30. Teacher evaluation focus. (n=158)	2.74	2.97	2.82	3.00	2.93	2.94

Table 6 Mean value for various groups of respondents (Male, Female, Elementary teachers, Middle School teachers, and High School teachers) in the Culture arena

Context. Questions 31-37 of the survey dealt with items from the Context arena of change. Respondents were asked to what extent these items inhibited their ability to implement Engineering Design; from 1 = no extent, this factor does not inhibit my ability to implement Engineering Design; 5 = to a great extent, this factor greatly inhibits my ability to implement Engineering Design. Mean scores on the items related to context range from 1.90 to 2.63, reflecting respondents' perceptions that these items were not inhibiting their ability to implement Engineering Design to the same extent that the Competencies, Conditions, or Culture arenas. The item from the Context section noted as having the greatest effect on respondents ability to implement Engineering Design was community understanding of Engineering Design, with 28.8% of respondents choosing a four or a five. Results from the Context section of the survey are summarized in Table 7 below.

Context: To what extent, if any, do the following inhibit your ability to implement Engineering Design activities in your classroom, right now?
1= no extent, this factor does not inhibit my ability to implement Engineering Design;
5= to a great extent, this factor greatly inhibits my ability to implement Engineering Design

Question	**1= No Extent**	**2**	**3**	**4**	**5= great extent**	**Mean**	**SD**
31. Lack of parental support for learning. (n=158)	58	41	34	19	6	2.20	1.17
	36.7%	26.0%	21.5%	12.0%	3.8%		
32. Lack of school and community trust. (n=158)	68	49	25	12	4	1.96	1.06
	43.0%	31.0%	15.8%	7.6%	2.5%		
33. Concerns of parents. (n=156)	66	47	28	12	3	1.97	1.04
	42.3%	30.1%	18.0%	7.7%	1.9%		
34. Concerns of community members. (n=155)	69	49	24	10	3	1.90	1.01
	44.5%	31.6%	15.5%	6.5%	1.9%		
35. Community and school standards for success are not in agreement. (n=158)	58	42	29	21	8	2.23	1.21
	36.7%	26.6%	18.4%	13.3%	5.1%		
36. Standards for success in school are too low. (n=157)	65	46	27	10	9	2.06	1.18
	41.4%	29.3%	17.2%	6.4%	5.7%		
37. Community understanding of Engineering Design. (n=157)	41	37	37	23	19	2.63	1.33
	26.1%	23.6%	23.6%	14.7%	12.1%		

Table 7 Data collected from the Engineering Design Implementation Survey focusing on the Context arena

When the data is disaggregated into male or female groups, or into groups based on the level the respondents teach (Elementary, Middle School, or High School) the differences in the Context arena are not very great. Furthermore, none of the context factors are noted with a mean greater than 3 from any group, and some are below 2. This cannot be interpreted to mean that contextual issues are not barriers to Engineering Design implementation at all schools. But it may mean that addressing other issues will produce greater improvements more swiftly. Table 8 below summarizes these results.

Context: To what extent, if any, do the following inhibit your ability to implement Engineering Design activities in your classroom, right now?
1= no extent, this factor does not inhibit my ability to implement Engineering Design;
5= to a great extent, this factor greatly inhibits my ability to implement Engineering Design

Question	Male	Female	Elem	MS	HS	Universal Mean
31. Lack of parental support for learning. (n=158)	2.06	2.20	2.06	2.17	2.24	2.20
32. Lack of school and community trust. (n=158)	1.80	1.95	1.84	1.83	1.99	1.96
33. Concerns of parents. (n=156)	1.88	1.91	1.80	1.86	2.00	1.97
34. Concerns of community members. (n=155)	2.04	1.85	1.71	1.90	1.89	1.90
35. Community and school standards for success in school are not in agreement. (n=158)	2.24	2.15	2.06	2.31	2.22	2.23
36. Standards for success in school are too low. (n=157)	2.24	1.93	1.76	1.79	2.33	2.06
37. Community understanding of Engineering Design. (n=157)	2.61	2.62	2.90	2.45	2.48	2.63

Table 8 Mean value for various groups of respondents (Male, Female, Elementary teachers, Middle School teachers, and High School teachers) in the Context arena

Open-ended Response. Respondents were asked, “What other factors do you see as inhibiting your ability to implement Engineering Design in your classroom this year?” This qualitative survey item was part of the design of the study, meant to provide information beyond the responses predetermined by the author. It allowed respondents an opportunity to speak their individual concerns. Several new viewpoints were presented in this section. And, although the question asked for *other* factors, many respondents chose to repeat items that had already appeared in the survey. Table 14 found in Appendix B lists the responses to that question.

The open-ended responses were placed in categories and the number of respondents choosing a factor within that category were compiled. Several respondents stated more than one response. In those cases, their response was placed in both categories. An analysis of those responses shows that district and building priorities was the factor noted most often for inhibiting a teacher's ability to implement Engineering Design (20). Lack of professional development (15), lack of time for planning in the school day (13), and lack of time for science instruction in the school day (12) were also identified as factors that inhibit a teacher's ability to implement Engineering Design. Lack of supplies, equipment, and funding was the category with the next most oft cited response (9). Table 9 on the next page summarizes the results of that open-ended question.

Question 38: What other factors do you see as inhibiting your ability to implement Engineering Design in your classroom this year?

Category	# of Respondents
NP- New Priorities for the district, Building, and curriculum	20
PD- Professional development	15
TP- Time for planning	13
TS- Time for science in school day	12
$- Supplies/equipment/funding	9
CS- Collegial support	5
S- Space	4
O- Other	8
NO- There are no factors or no other factors	9

Table 9 Responses to an open-ended question on other factors that inhibit the implementation of Engineering Design.

Discussion

Generally, the Competencies, Conditions, and Culture sections illustrated greater urgency to the factors, with higher mean scores. A higher score is interpreted as a greater number of respondents chose to mark it closer to the "greatly inhibits my ability to implement Engineering Design" side of the likert scale. Each of the four change arenas will be discussed in turn, followed by a summation of the analysis.

Competencies. The data from the competencies arena of change indicates wide differences among respondents. Just over 25% of the respondents state that their familiarity with Engineering Design *greatly inhibits* their ability to implement Engineering Design, while nearly 18% say that this has *no effect*. The responses to reading literature on Engineering Design are very similar. Nearly 30% of respondents state that their lack of college coursework of appropriate focus *greatly inhibits* their ability to implement Engineering Design, while over 16% state that this has *no effect*. Clearly a large percentage of respondents state that their lack of capacity – for whatever reason – greatly effects their ability to implement Engineering Design. The best option for building capacity is professional development- and this, too, is borne out in the survey. Over 30% of the respondents (nearly one third) stated that their lack of professional development focused on Engineering Design *greatly inhibits* their ability to implement Engineering Design. Teachers' experience level with Engineering Design was at a similar measure.

So, how are teachers to gain experience with this innovative practice that they have not had in college, nor read articles about. Focused, imbedded, long-term professional development; led by experts, would be an appropriate response.

Conditions. Many of the items that are from the Conditions change arena are items that an individual teacher feels are difficult for them to address directly. These are items such as, how much time is allotted for teacher planning during the school day, how much time is allotted for science class in the school day, how much funding is there for science supplies and equipment, and even the prior experience level of the students that come to their classroom. These same items received high percentages of *greatly affect* my ability to implement Engineering Design. These items are the items that building and district leaders can change most directly.

That is not to say that these items can be changed easily. Increasing the time allotted for teacher planning affects the amount of time spent by teachers elsewhere- and usually it is removed from direct instruction time with the students. Increasing the time allotted for science in the school day means taking time away from some other subject- or increasing the length of the school day. Shifting more resources and funding to science budgets means taking that money away from some other budget. None of these changes is a change made easily. But, with an analysis (such as this paper) for clarity in the discussion, appropriate and transparent changes can be made in all of these areas. This change in science education starts with the premise that science education ought to be improved, works with diligence to analyze the education system (as presented in this paper), moves to communicate openly and transparently with all stakeholders, and presses forward with conditions that will support improvements to science education.

Culture. The building (and district) culture can be a difficult arena of change. These items are important but seem nebulous and ethereal like trust, belonging, or the concept of warmth. Other items of the Culture arena can be more easily and directly affected by building and district level leadership; such as district or building priorities. District priorities was the item most often cited by teachers as, *greatly affecting* my ability to implement Engineering Design. District priorities are determined by the superintendent (in concert with the school board and the leadership team chosen by the superintendent). Choosing a short list of narrow-focused priorities can be one of the greatest tools for change wielded by an able superintendent.

This aspect of the culture, so directly affected by the top of the district leadership, has widespread affects in many other areas. If a superintendent has chosen to focus on improving science instruction, it follows that the superintendent may: increase the funding to the science budget, allocate more time in the school day to science instruction, allocate more time for planning for science teachers, provide expert-led professional development for science education, etc. Thus, the district leadership in the Culture arena can have profound affects in the Conditions and Capacities arenas. It must be this way. If the district leadership declares that improving science education is a priority, but does nothing to support changes in Conditions or Capacities there will be no change at all. If anything, the staff will begin to expect nothing but "lip service" to changes needed by the district. That will lead to a profound downward spiraling of moral with far-reaching and detrimental consequences.

Context. Information from the Context arena of change illustrated that these items are not of urgent concern to the district leadership. Fewer than five percent of respondents chose any item from this arena as, *greatly affecting* my ability to implement Engineering Design. For most of these items over 40% of respondents declared they had no affect on teachers' ability to implement Engineering Design. From this information, district leadership can conclude that their efforts and time should be spent in the other arenas of change.

Open-ended Responses. Data from the last open-ended question support the information gathered in the quantitative sections in terms of the four arenas of change as identified by Wagner et al. (2006). Of the five categories with the highest frequency, three are from the change arena of Conditions (time for preparation, time for science in the school day, and equipment, supplies, and funding), and one is from Competencies (more professional development), and one is from Culture (district priorities).

Section VI: Vision of Success, To - Be

The vision of successful Engineering Design implementation is one that will bring about full implementation and integration of Engineering Design; facilitating and empowering all stakeholders for excellence in science education. Utilizing Wagner, et al.'s systems approach (2006), a discussion of the vision for success in the arenas of competencies, conditions, culture, and context follows.

Competencies

The vision of success in the arena of Competencies is one where the faculty are familiar, trained, informed, competent, and comfortable using Engineering Design in every science course and every elementary level. Faculty would have on-going, imbedded, relevant, and authentic professional development from experts on using Engineering Design in their classes. Students would be experiencing the benefits of real-world engineering practices in learning science at every level, K-12; each successive year building cyclically on the previous year's successes.

Conditions

The vision of success in the arena of conditions is one where faculty have enough time devoted to science class that they can undertake Engineering Design focused units at several points in each year. They have time to plan and evaluate new activities and the new curriculum with their colleagues. There is funding to support these novel practices, including sufficient equipment and supplies. The vision includes enough space to store materials between uses, as well as space for student projects during the day. There will be valid assessments that are in alignment with state assessments and that give teachers and students important feedback on student progress. Students can feel the support for the program as they undertake each challenge.

Culture

The vision of success in the arena of culture is one where students, teachers, and administrators have high expectations for student achievement. The focus of the district is one of excellence in education, including science education and Engineering Design. This focus is part of the building culture, and anyone walking into the building is aware of this focus. There are a few initiatives in the building and district- but they are all a part of building student achievement. Demands for “better test scores” have been replaced by a concerted effort to increase student achievement and college and career readiness; and Engineering Design became an important part of this effort.

Context

The vision of success in the arena of context is one of partnership throughout the many levels of community. There is a shared vision of success for the students and success for the school throughout the building, the district, the local community, the state, and beyond. Responsibility is widely recognized as being shared between all levels of community. When difficulties arise there is a spirit of collaborative creativity to solve them. There is transparency and trust at every level of organization, and many avenues for fruitful communication throughout. This open and trusting networked community has been a key component of providing resources necessary for Engineering Design Implementation.

Survey Results in Support of the Vision

On questions 39 – 49 of the Engineering Design Implementation survey, teachers were asked to look ahead to their school pursuing full implementation of Engineering Design. Then they were to choose a descriptor for how valuable that factor would be in implementing Engineering Design, choosing 1 = not of any value, this factor will not aid in the successful implementation of Engineering Design in my classroom; 5 = very valuable, this factor will greatly aid the successful implementation of Engineering Design in my classroom. The range of mean scores on these items was from 3.21 to 4.20, illustrating that every item on the list was perceived as being of value to many teachers. Of all of these important factors, students' increased abilities in math and reading were less often noted for value, with 39.5 and 40.3% choosing to respond with a four or a five.

Of all of these factors noted for their importance in full implementation of Engineering Design, professional development was chosen the most often for the factor of most value. 83.3% of the respondents assigned it a four or five, with almost half of the respondents choosing five, very valuable. Other factors that had a high percentage of respondents choosing a four or a five included re-prioritization of resources (67.8%), state acceptance of NGSS (63.1%), and initiatives being sustained for five or more years (61.7%). Table 10 on the next page summarizes responses to these items.

Looking ahead, and imagining this school pursuing full implementation of Engineering Design within NGSS, please choose a descriptor for how valuable each of these actions will be toward that goal.
1= not of any value, this factor will not aid in the successful implementation of Engineering Design in my classroom
5= very valuable, this factor will greatly aid the successful implementation of Engineering Design in my classroom

Question	**1= Not of Any Value**	**2**	**3**	**4**	**5= very valuable**	**Mean**	**SD**
39. Re-prioritization of district goals. (n=148)	16 10.8%	19 12.8%	38 25.7%	39 26.4%	36 24.3%	3.41	1.29
40. Re-prioritization of building goals. (n=148)	14 9.5%	19 12.8%	44 29.7%	36 24.3%	35 23.7%	3.40	1.23
41. Initiatives sustained for 5 or more years. (n=149)	11 7.4%	14 9.4%	32 21.5%	48 32.2%	44 29.5%	3.68	1.19
42. State acceptance of NGSS. (n=149)	14 9.4%	14 9.4%	27 18.1%	35 23.5%	59 39.6%	3.74	1.32
43. Provision of effective professional development. (n=149)	7 4.7%	5 3.4%	13 8.7%	50 33.6%	74 49.7%	4.20	1.05
44. State determination of a valid assessment of Engineering Design. (n=149)	12 8.1%	21 14.1%	24 16.1%	48 32.2%	44 29.5%	3.61	1.26
45. District determination of a valid assessment of Engineering Design. (n=149)	13 8.7%	19 12.8%	26 17.5%	52 34.9%	39 26.2%	3.57	1.24
46. Re-prioritization of resource allocation to support Engineering Design. (n=149)	9 6.0%	8 5.4%	31 20.8%	51 34.2%	50 33.6%	3.84	1.14
47. Students gain prior experience in Engineering Design. (n=149)	6 4.0%	15 10.1%	48 32.2%	47 31.5%	33 22.2%	3.58	1.08
48. Students have an increased reading ability. (n=149)	15 10.1%	22 14.8%	52 34.9%	36 24.2%	24 16.1%	3.21	1.18
49. Students have an increased math ability. (n=147)	13 8.8%	21 14.3%	55 37.4%	31 21.1%	27 18.4%	3.26	1.19

Table 10 Respondents' value assignment for factors that would support successful implementation of Engineering Design.

When the data is disaggregated into male or female groups, or into groups based on the level the respondents teach (Elementary, Middle School, or High School) the differences in the value for specific changes that might be of value in the implementation of Engineering Design are not very great. Thus, the value of these factors is a source of agreement across levels of teaching and gender. It is also worth noting that provision of effective professional development had the ranking of greatest value for each group. Table 11 on the next page summarizes these results.

Looking ahead, and imagining this school pursuing full implementation of Engineering Design within NGSS, please choose a descriptor for how valuable each of these actions will be toward that goal.
1= not of any value, this factor will not aid in the successful implementation of Engineering Design in my classroom
5= very valuable, this factor will greatly aid the successful implementation of Engineering Design in my classroom

Question	Male	Female	Elem	MS	HS	Universal Mean
39. Re-prioritization of district goals. (n=148)	3.33	3.43	3.71	3.24	3.27	3.41
40. Re-prioritization of building goals. (n=148)	3.37	3.43	3.73	3.10	3.32	3.40
41. Initiatives sustained for 5 or more years. (n=149)	3.71	3.66	3.84	3.38	3.71	3.68
42. State acceptance of NGSS. (n=149)	3.63	3.83	3.92	3.59	3.75	3.74
43. Provision of effective professional development. (n=149)	4.12	4.24	4.22	3.97	4.33	4.20
44. State determination of a valid assessment of Engineering Design. (n=149)	3.41	3.72	3.94	3.31	3.54	3.61
45. District determination of a valid assessment of Engineering Design. (n=149)	3.37	3.68	3.84	3.34	3.51	3.57
46. Re-prioritization of resource allocation to support Engineering Design. (n=149)	3.65	3.92	4.04	3.66	3.79	3.84
47. Students gain prior experience in Engineering Design. (n=149)	3.53	3.61	3.88	3.28	3.54	3.58
48. Students have an increased reading ability. (n=149)	3.22	3.24	3.33	3.10	3.26	3.21
49. Students have an increased math ability. (n=147)	3.25	3.31	3.29	3.47	3.38	3.26

Table 11 Mean value for various groups of respondents (Male, Female, Elementary teachers, Middle School teachers, and High School teachers) when asked to rate the value of certain actions to bring about successful implementation of Engineering Design.

Open-ended Results in Support of the Vision

Respondents were asked an open-ended question, what other actions do you see as having value in the successful implementation of Engineering Design in your classroom? This qualitative survey item was part of the design of the study, meant to provide information beyond the responses predetermined by the author. It allowed respondents an opportunity to speak their individual concerns. Several new viewpoints were presented in this section, but many respondents chose to emphasize items previously noted. Responses to this question are given in Table 15 in Appendix C.

After placing the open-ended responses into categories and tabulating those categories, it becomes clear that professional development is seen as the key for successful implementation of Engineering Design. A summary of these results is in Table 12 on the next page.

Question 50: Other actions that will have value in the successful implantation of Engineering Design in your classroom; please list and choose a descriptor for importance.

Category	# of Respondents
PD- Professional Development	15
$- Supplies/Equipment/Funding	10
NP- New Priorities for the district, Building, and curriculum	9
TP-Time for Planning	8
SP- Student Preparation	4
TS- Time for Science in the school day	3
NGSS- State adopts NGSS	2
SCS- Smaller Class Size	2
S- Space	1
O- Other	8
NO- None or No Other actions	5

Table 12 Categories of actions that have value in Engineering Design implementation.

This vision of successful Engineering Design Implementation goes far beyond merely adding one more item to the list of tasks for teachers. Engineering Design is a framework based on creativity, collaboration, and authentic problem solving. It is a practice that students inherently find relevant to their lives and future careers. It is engaging and "fun". It is the antithesis of the lecture and handout format. More than just the science component of Common Core, it is the science component to bridging the Global Achievement Gap (Wagner, 2010). Engineering Design Implementation plays a crucial role in the success for all students.

Section VII: Strategies and Actions for Change

In the results section, an up-to-date description of the educational system was presented with respect to Engineering Design Implementation. In the just previous section, Vision of Success, the components of the educational system were presented in the perfection of Engineering Design Implementation. In this section on Strategies and Actions for Change, a multi-faceted action plan is presented that would take the educational system from where we are now to where we need to go. In the case of Engineering Design implementation, it will take us from a place where faculty are generally poorly prepared to teach Engineering Design, where conditions of lack of time and money impede the utilization of Engineering Design, and where district and school priorities do not include Engineering Design; to a place where the practice of Engineering Design is taught with excellence at all levels, and where students are reaping the benefits of that instruction.

Further information on what respondents perceived as the single most important action that would advance Engineering Design implementation was the subject of questions 51 and 52 on the survey. Although respondents were asked to provide a single most important action, their responses tend to yield the same blueprint that has been discussed throughout this analysis; that of provision of professional development, changes in district priorities, increases in funding for equipment and supplies for science, increases in planning time, increases in time for science instruction. Yet again, professional development was chosen most often as the item of most value in the successful implementation of Engineering Design. Additionally, many singled out the need for the state to adopt NGSS. It is apparent to most teachers that adoption of NGSS by the state will serve to influence district priorities. The responses from questions 50 and 51 are listed in Table 16, Appendix D.

A summary of the categories from question 51 is presented below in Table 13.

Question 51: What is the single most important change needed to advance Implementation of Engineering Design?

Category	**# of Respondents**
PD- Professional Development	29
NP- New Priorities for the district, Building, and curriculum	25
$- Supplies, equipment, and funding	18
NGSS- State adopts NGSS	13
TP- Time for Planning	10
TS- Time for Science in school day	9
CTA- Change in Teacher Attitudes	7
SP- Student Preparation	5
O- Other	4

Table 13 Respondents' most important change needed to advance implementation of Engineering Design

Competencies

The competencies facet of this educational system is most easily addressed by professional development. Ideal professional development is imbedded, long-term, relevant, authentic, and taught by experts (Drago-Severson, 2009; Knowles, Holton, &

Swanson, 2011). Quality professional development is an absolute must to bridge the gap from the “what is” to the “to be”. As professional development was the greatest response from many facets of this survey, it is the easiest choice – it must be foremost in the Change Leadership plan. However, when our educational communities are seen as systems, merely adding professional development will not be enough. Other actions will need to support the efforts of the teachers in addition to the growth in capacity. It is clear that changes in the Conditions and Culture arenas will need to take place simultaneously.

Condition

In the Conditions arena of change, there are several factors to be addressed. The largest factor is the issue of time. Also there is the issue of funding for supplies and equipment. Space for students to store their projects is an additional factor that ought be addressed. Choosing a valid assessment instrument that aligns with the state’s assessment is also an important factor in the Condition arena.

The greatest strategy for change in the conditions arena is to choose a representative committee that is empowered to make changes. This committee’s members and work must be completely transparent. The members should be made up of science teachers (depending on the district), elementary teachers (depending on the district), and administrators from the building and district level. This committee should creatively and collaboratively address issues of time for teacher planning, time in the school day for science, funding for equipment and supplies for science, space for science teachers, curriculum modifications that will incorporate Engineering Design, and the development of an assessment instrument for Engineering Design.

Culture

In the arena of Culture, it is important to build the culture of high expectations for excellence in science instruction. That means there should be an adjustment of priorities, not merely an addition to a long list of priorities. There should be a few very focused priorities, and Engineering Design implementation needs to be one of them. This priority can benefit from state determination of NGSS as a priority. If the state has not moved to adopt NGSS, it is more difficult to convince school district leadership that it ought to be a priority. Similarly, if Engineering Design is not a component of the mandated state testing, it will not be a priority for the school district.

In terms of the strategy for change in this arena, actions which speak to the district commitment to a few initiatives speak volumes. From the very first administrative council meeting, from the very first faculty meeting; to the agenda items on later meetings, there should be a conscious effort and emphasis on just a few initiatives- one of them being Engineering Design implementation.

Finally, it is interesting to note that a separate issue from the Culture arena surfaced in the open-ended question, question 51. A small but non-zero percentage of respondents noted that a change in teacher attitudes was the single most important factor for successful implementation of Engineering Design. Presumably, a change in the teacher's attitude would be accompanied by those actions on the part of the teacher that would result in the successful implementation of Engineering Design.

Context

In the change arena of Context, development of high expectations and shared responsibilities are a must (Wagner et al., 2006). When the interlocking contexts of parents, teachers, administrators, and community are all on the same page and working together, great things can be accomplished. When striving to build consensus, communication of priorities and rationale is key. These kinds of items lend themselves to Principals' and Superintendents' advisory boards, where community members can regularly and transparently interact with different levels of educational leaders.

Personal Reflection

I undertook this particular study because of the personal connection I have to Engineering Design. I have been collaboratively developing, writing, utilizing, teaching, leading, creating, and promoting Engineering Design for decades. It has always been a source of joy to teach my students or my fellow teachers with Engineering Design. As Engineering Design is now the central piece of my dissertation, I can state that I am actively involved in leading Engineering Design implementation on several fronts – my Change Plan is an action plan and an advocacy plan. I am providing professional development to several districts in the form of a series of workshops that I created and lead. I am providing leadership to a district that asked for my assessment and evaluation of a part of their science curriculum. I am providing leadership in creatively collaborating on implementing Engineering Design in a separate high school district in the Midwest. And I am providing leadership across a very broad portion of the educational community through authorship and conference presentation. I co-authored an article that has been published in the *Journal of Chemical Education*, Microbeads and Engineering Design in Chemistry: No Small Educational Investigation (Hoffman & Turner, 2015). That article is based on activities my co-author and I instituted to bring Engineering Design to our students at the collegiate level. So, my actions are local and national. I also presented my research at the Iowa Academy of Science conference in 2014, and at the national conference of National Science Teachers Association and the Wisconsin Innovative Schools Network in 2015. These efforts to initiate and sustain the changes necessary for successful Engineering Design implementation will be further discussed in the Advocacy portion of my dissertation.

Section VIII: Conclusion

There is an urgent need for better science instruction at all levels, K-12. Engineering Design is an important part of that better science instruction in addition to being an excellent companion piece to the Seven Survival Skills espoused by Wagner (2010). It is also an innovative problem-based, engineering practice and the science component of Common Core. Educational change is an adaptive challenge (Heifetz, Grashow, Linsky, 2009), and complex enough that a systems approach is warranted (Wagner et al., 2006). The systems approach was the guiding principle of this manuscript's survey and its data, analysis, and evaluation. This study set out to answer several questions, the answer to each of which is summarized below.

1. What are the barriers to implementation of Engineering Design as noted by various K-12 teachers?

Teachers note barriers of lack of training, not enough time to meet and plan with other teachers, lack of funds for equipment and supplies, lack of Engineering Design activities; in addition to students not having adequate prior experiences. Barriers also include lack of college preparation in pre-service courses and lack of professional development.

2. What is the relative importance of those barriers?

Using the greatest mean on the survey items as a guide to their relative importance, teachers perceive a lack of time for planning (4.00) and lack of time for meeting with teacher teams (3.76) as the two most critical barriers. The lack of Engineering Design activities for their course is also noted as an important barrier (3.57). Lack of student prior experiences (3.37), the need for more supplies and equipment (3.36, 3.33), insufficient college course work (3.36), and lack of professional development directed towards Engineering Design were also perceived as barriers to Engineering Design implementation.

When asked the same type of question in an open-ended format, teachers responded with building and district priorities and lack of professional development as the key factors inhibiting Engineering Design implementation.

3. What factors do teachers see as solutions to the barriers in implementing Engineering Design?

Teacher perceived solutions for the barriers to Engineering Design include state-level and district level issues on priorities of NGSS, as well as sustaining district initiatives for five years or more and providing professional development.

4. What is the relative importance of those solutions?

Using the greatest mean on the survey items as a guide to their relative importance, teachers widely regard professional development as the most important solution (4.20). District re-prioritization of resources is also very important (3.84). State actions to accept NGSS (3.74) and choose a valid assessment (3.61) were very important. Having district initiatives sustained for more than five years was another very important solution (3.68).

The relative importance of solutions for Engineering Design implementation from the quantitative section of the survey is echoed by the qualitative results from the open-ended questions; where professional development, supplies/equipment/funding, and making Engineering Design a priority were the most frequent responses. Presumably, if the district makes Engineering Design a priority, increases in funding will occur that provide more supplies and equipment.

Teachers desire to implement Engineering Design in their classrooms, but they perceive barriers to this implementation (Turner, 2015). Provision of strong professional development opportunities to build capacity, coupled with re-prioritization of resources (including time) offers the best pathway for Engineering Design implementation- and increases in excellence in science education.

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Appendix A

Implementation of Engineering Design Survey

(Some changes to format are present due to the differences between Microsoft Word and Survey Monkey.)

Engineering Design
Implementation

Engineering Design: to define problems—situations that people wish to change—by specifying criteria and constraints for acceptable solutions; generating and evaluating multiple solutions; building and testing prototypes; and optimizing a solution. (NGSS, 2013)

RIGHT NOW

Please circle a number that corresponds to the frequency of the activity in the last two years.

1= never true, 2= once or twice, 3 = three times, 4= four times, 5= five or more times

1. I have spent time with my colleagues discussing the implementation of Engineering Design in our curriculum in the last two years.
   1. 2 3 4 5
2. I have read journal articles/books on Engineering Design for science education in the last two years.
   1. 2 3 4 5
3. I have attended a conference/workshop focused on Engineering Design in the last two years.
   1. 2 3 4 5
4. I have participated in other forms of professional development directed toward Engineering Design in the last two years. (Please list below.)

5. I am familiar with the Next Generation Science Standards.
   1= not at all familiar, 5= very familiar
   1 2 3 4 5
6. I am familiar with the Engineering Design component of the Next Generation Science Standards.
   1= not at all familiar, 5= very familiar
   1 2 3 4 5

Capacity

To what extent, if any, do the following inhibit your ability to implement Engineering Design activities in your classroom, right now?

1=no extent, this factor does not inhibit my ability to implement Engineering Design;
5= to a great extent, this factor greatly inhibits my ability to implement Engineering Design

7. My familiarity with Engineering Design
   1 2 3 4 5
8. My professional development focused on Engineering Design.
   1 2 3 4 5
9. My reading of literature on Engineering Design.
   1 2 3 4 5
10. My lack of college coursework focused on Engineering Design.
    1 2 3 4 5
11. My experience level with Engineering Design.
    1 2 3 4 5

Working Conditions

12. Not enough time allotted for planning in the school day
    1 2 3 4 5
13. Not enough time allotted for meeting with teacher teams
    1 2 3 4 5
14. Not enough time allotted for science class in the school day.
    1 2 3 4 5
15. Not enough days allotted for school in the school year
    1 2 3 4 5
16. Space in my classroom is insufficient
    1 2 3 4 5
17. Need for more equipment (one time purchase)
    1 2 3 4 5
18. Need for more supplies (every year purchase)
    1 2 3 4 5
19. Class size is too large
    1 2 3 4 5
20. Lack of Engineering Design assessments in my course
    1 2 3 4 5
21. Lack of Engineering Design activities for my course
    1 2 3 4 5
22. Student abilities in math are too low
    1 2 3 4 5
23. Student abilities in reading are too low
    1 2 3 4 5
24. Student prior experience in Engineering Design are insufficient
    1 2 3 4 5

Culture/Collegiality

25. Lack of trust with colleagues
    1 2 3 4 5
26. Lack of trust with building administration
    1 2 3 4 5
27. Building climate
    1 2 3 4 5
28. Current district priorities
    1 2 3 4 5
29. Current building priorities
    1 2 3 4 5
30. Teacher Evaluation focus
    1 2 3 4 5

Context

31. Lack of parental support for learning
    1 2 3 4 5
32. Lack of school and community trust
    1 2 3 4 5
33. Concerns of parents community members
    1 2 3 4 5
34. Concerns of community members
    1 2 3 4 5
35. Community and school standards for success in school are not in agreement
    1 2 3 4 5
36. Standards for success in school are too low
    1 2 3 4 5

37. Community understanding of Engineering Design
    1 2 3 4 5

38. What other factors do you see as inhibiting your ability to implement Engineering Design in your classroom this year? (Please list and choose a descriptor for how great of an affect this factor is having.)

LOOKING AHEAD

Looking ahead, and imagining this school pursuing full implementation of Engineering Design within NGSS, please choose a descriptor for how valuable each of these actions will be toward that goal.

1= not of any value, this factor will not aid in the successful implementation of Engineering Design in my classroom
5= very valuable, this factor will greatly aid the successful implementation of Engineering Design in my classroom

39. Re-prioritization of district goals
    1 2 3 4 5
40. Re-prioritization of building goals
    1 2 3 4 5
41. Initiatives sustained for 5 or more years
    1 2 3 4 5
42. State acceptance of NGSS
    1 2 3 4 5
43. Provision of effective professional development
    1 2 3 4 5
44. State determination of a valid assessment of Engineering Design
    1 2 3 4 5
45. District determination of a valid assessment of Engineering Design
    1 2 3 4 5
46. Re-prioritization of resource allocation to support Engineering Design
    1 2 3 4 5
47. Students gain prior experience in Engineering Design
    1 2 3 4 5
48. Students have an increased reading ability
    1 2 3 4 5
49. Students have an increased math ability
    1 2 3 4 5

50. Other actions that will have value in the successful implementation of Engineering Design in your classroom; please list and choose a descriptor.

51. What is the single most important change needed to advance implementation of Engineering Design?

52. Why is the above change so urgent and important?

53. Are there any other items you need to add?

Info on the teacher

54. Gender	A. Male B. Female
55. Present Grade Level(s) taught	A. Elementary B. 7th-8th grade C. 9th-12th grade
56. Experience in teaching	A. less than 5 years B. 6-10 years C. 11- 15 years D. 16- 20 years E. 21 – 25 years F. Over 25 years
57. Experience in present building	A. less than 5 years B. 6-10 years C. 11- 15 years D. 16- 20 years E. 21 – 25 years F. Over 25 years

Appendix B

Table 14

38. What other factors do you see as inhibiting your ability to implement Engineering Design in your classroom this year? (Please list and choose a descriptor for how great an affect this factor is having.) (n= 78)
• Training and not up to date on curriculum and NGSS standards in district. What I do is on my own. (PD) • Lack of supplies ($) • Uncertainty about state direction on acceptance of the standard (NP) • None (9) • Already stated. Time in class (41 minutes) and district emphasis (ACT and AP tests) (TS,NP) • The main item is planning and collaboration time to focus on Engineering Design. With Educator Effectiveness and other building level items, our PLC time is eaten up. (TP) • Not enough time to do everything that is expected of teachers and still provide students with the support they need. (NP) • I believe there needs to be better partnerships with the IHE and Business to support the engineering standards (CS) • Focus is reading and math. Science gets the very little time that's left so time and energy are spent elsewhere. (TS) • Not enough student interest (O) • A huge part is designing learning outcomes and assessment tools for the engineering project that targets content standeards. Otherwise, there is just limited time to allow kids to explore, design, make mistakes, evaluate and redesign; all the while keeping engagement (by designing something productive) and hitting all the content and connecting big concepts that are intertwined within the project design project. How to balance the project with the content so it is effective is difficult. Furthermore, the getting materials, and instrumentation that is precise and quality enough to design anything with real meaning cost money. Setting up, clean up, storage for ongoing projects are also issues. Time for reading science literature, writing explanations, and doing it well, etc. All severely inhibit major engineering projects. (NP,TS,$,S,TP) • None (NO) • We have a "canned " curriculum for science (FOSS). We are supposed to get through 4 modules per year, however all of your classroom guidance and any specials have to come out of science or social studies time. I have taken many engineering design classes in the past and would love to implement them into my curriculum, but I don't have enough time to teach my regular curriculum. (TS) • Biggest issue is time needed to implement successfully in all the different classes I teach. (TS) • The State of (removed by evaluator) not adopting the NGSS is the factor of highest impact. The School Board will not allow for NGSS adoption- second highest factor. (NP) • I have a harder time finding engineering activities that connect well to geology at the middle school level. There are so many standards in geology that need to be taught that I don't feel I have time for additional activities. Materials and space are also a problem. (NP,S) • Not knowing enough about them and how to teach them. (PD) • Students lack of background knowledge with inquiry process because the focus at the younger levels is so much on reading and math, science is often not covered. Its not until middle school (around 6th grade) students have science daily. This is a significant factor. We are to not only focus on the science standards, but also the ELA standards and some math, too. The time issue has a significant impact. (TS,NP) • I/We need professional development. As far as I know, our district does nothing with Engineering Design. It may happen at the High School level, and I'm just not aware of it. (PD) • I am not familiar with Engineering Design, so it is difficult to respond whether our district or even our department is receptive. We have not adopted common core as a district because of the

political issues with the state. Not sure if Engineering Design is related. (PD,NP)

- I am not sure what level Engineering Deign would be taught. I teach 5th grade- would it start here? (PD)
- Familiarity. (PD)
- My confidence is a huge factor in keeping me from implementing. (PD)
- One of the main issues is developing the program and the front costs to do so. My school does not have a lot of money and I am given $400 general fund for my 6th grade to 12th grade sciences. That does not allow for Engineering Design to take place. I hardly have enough money to conduct regular experiments. ($)
- None (NO)
- District implementation is limited due to funds ($)
- I am fortunate that I am the only one that teaches my courses. I have the latitude to try and evaluate the effectiveness of the activities I create. The only obstacle is the time I have to spend on development of activities. (TP)
- District has not adopted NGSS yet, nor has the state. Testing does not align with engineering discussions/problem solving. (NP)
- The biggest concern is lack of time given to science during the school day, especially in K-5 but also in middle school. (TS)
- I do implement Engineering Design in the classroom and have been doing it for years. (9)
- Professional Development on integration of Engineering Design. (PD)
- None (9)
- Too many other things to implement right now; too many reforms all at once. (NP)
- Is science the best place to be teaching engineering because of the content and the true nature of engineering curriculum? (CS)
- Teaching virtually always is a challenge in teaching engineering and design. I wish I had access to more online opportunities for students to design virtually. Physical design is time consuming and I would like to have alternatives. (TS)
- The fact that I am a first year teacher is a great contributing factor. (PD)
- Time to implement in the classroom given that design hasn't been made a priority as far as the standards that we test students for. (NP)
- The class schedule. I only see students for about 20 minutes of work time, 2 times a week for a semester. (TS)
- Time to learn, plan, and implement and the resources required for all of them. (TP)
- Only have about 20 minutes 3x a week for science/social studies. (TS)
- Principal does not know anything about politics. (O)
- The biggest factor that hinders my ability to adequately implement the engineering design is the time to set up and plan for the use of the materials. Our district does not give enough planning time during the day or in our school schedule. (TP)
- No time. No funds. NGSS, Common Core….TIME, TIME (TS,$,NP)
- New teacher. I need access to materials and information since I have no engineering experience. (PD)
- There are so many different initiatives that there is little time to add new content without removing other content. (NP)
- Budget and training are the two main factors. (PD,$)
- I am already putting in hours outside of the school day on a daily basis with so many new responsibilities being added. It makes it difficult for me to find time to research/find/implement design activities and make modifications to curriculum. (TP)
- I teach 5 different science classes occupying 7 class periods in an 8 class period day. TIME. TIME. TIME. Common Core, Educator Effectiveness taking time also. (TP,NP)
- Finding meaningful experiences that support the science curriculum and can be completed by students in a reasonable time. (TP)
- I do not teach classes covering this content, so most of these questions are not relevant to me or what I teach. This is the greatest textent factor. (O)
- "How will I meet the NGSS standards and implement Engineering Design all together?" I also

teach 6th grade science one day, then 7th grade science the next. Where am I to keep all the needed materials in a situation like this? (PD,TP,5)

- The lack of time to write curriculum to meet the NGSS standards that include Engineering Design, limited knowledge of the standards, and limited time to find resources. Also, the school day allows for only a limited amount of time for science. (TP,PD,TS)
- The state continues to add responsibilities, but never removes responsibilities. There is a disconnect between state student testing demands, teacher assessment, the political climate of the current education environment and a legitimate, well-rounded education for our students. Teachers need time to prepare for quality lessons across all curriculum areas, not just math and reading. Our current obsession with “grading” schools is to the detriment of our students’ well-rounded education. (NP)
- I see a lot of excuse language in teachers and school staff. There is no reason why teachers can not implement these best practices. (NO)
- None (NO)
- I’m a one person science department except for biology so I am the only person certified to teach chemistry, physics, and earth sciences so I already feel over loaded. (TP,NP)
- Time to make these changes (large) and curriculum connection (medium). (TP)
- Possibly having to purchase materials with my own money. Planning time ($,TP)
- Curriculum coordinator involvement in the process. (O)
- I do not teach science and the current science teacher I believe has no background. The factors do exist in math but I am not sure how to implement them in math. (PD)
- Other teachers in the course do not want to change and go towards this goal, and we have to all share one room. Others do not like as much activity or mess. There is also a lack of space for 8 classes of student projects. (CS,S)
- I feel that I have the freedom and resources to make the changes needed. It is now up to me to get it done. (NO)
- None (NO)
- District curriculum policies (NP)
- Our school day is so filled with busy work that revolves around the Educator Effectiveness and other administrative tasks that we don’t have the time or energy to collaborate or develop lessons. (TP,NP)
- I am preparing students for college chemistry. There are topics covered in college courses in the 1st quarter that I do not have time to teach my students. This is my priority. (NP)
- I have a degree in Civil Engineering. It requires a lot of problem solving and in-depth thought. The majority of my students struggle LOTS to understand basics. Reading comprehension is a constant battle. For many, that ‘reach’ in rigor is too much. (O)
- Lack of support from colleagues unwilling and closed off to exploring new and sometimes challenging approaches to education. (CS)
- Fiscal budgets, supplies, and teacher resources… ($)
- $$$$$$$$$$$$$$$$$$$$$ ($)
- Both middle school teachers are brand new to our district and still learning science curriculum (PD)
- In the process? (O)
- Lack of enough support from colleagues (whether it’s showing interest in what I’m doing or sharing/contributing ideas.) (CS)
- No time in math curriculum to do this (I am a math teacher). (O)
- We live in a manufacturing town. It would be a disservice to our community and local businesses to create such a focus on engineering. It is exhausting to have this focus of engineering coming down on us all the time. Problem solving is a valuable skill for every occupation, not just for engineers. Society seems to covet the engineer as the pinnacle of success. (O)
- The amount of time and energy being expended on the Teacher Effectiveness Project is extremely prohibitive of the creation of meaningful STEAM/STEM initiatives. (NP)

Table 14 Responses to the open-ended question of other factors that inhibit a teacher's ability to implement Engineering Design.

Appendix C

Table 15

50. Other actions that will have value in the successful implantation of Engineering Design in your classroom; please list and choose a descriptor for importance. (n= 58)
• Professional development opportunities (PD) • Reading and math skills (SP) • Working with all grade levels K-12 to integrate engineering into all aspects of the school day (NP) • Longer class periods- block scheduling (TS) • Space to store student projects that are underway is very limited. Access to computer- based testing equipment is not available. (S,$) • NA (NO) • The alignment of state assessments with the NGSS and state level adoption. (NGSS) • Time allotted to manage equipment. (TP) • The previous actions WOULD be beneficial, that is not to say that those are going to be implemented. • Teacher release time and support for Professional Development workshops on Engineering Design. (TP,PD) • Re-training and supplies (PD,$) • Training on how to intertwine the content into the project as well as assessment. (PD) • Time and money. (TP,$) • Getting back our time that we lost to teach science. We had 30min. daily allotted for science in the past. Now we have 45 min. every other day. (TS) • A curriculum that can combine the Engineering Design with the geological concepts. (PD) • Allotted time and priority (TS,NP) • Allocating money for curriculum and resources. We looked at STEM and PLTW, but they were too expensive or the training seemed to overbearing. ($) • Teaching social skills-working with others, dealing with conflict- important for classroom management.(O) • Professional development- Extremely important (PD) • Not sure of an answer… am not going to google Engineering Design…now (PD) • Money ($) • Time is very important. Training is very important. (TP,PD) • Students will learn scientific inquiry- This allows students to problem solve and to work through their misunderstandings to find a solution. (SP) • Integrate Engineering Design within the existing curriculum. It cannot be an add-on. (NP) • I am working on a partnership with our district and MSA Professionals, an engineering firm in our town. Engineers will come into our classrooms and help students with engineering projects. (O) • School board adoption of NGSS. (NP) • District, state support for Engineering Design implementation in the classroom. (NP,NGSS) • Not losing the class to 8th grade. It won't be taught that way there. (Physical Science) (O) • District importance placed on Engineering Design (NP) • More time for learning and implementation for the teacher (PD,TP) • None (NO) • None- covered in the questions (NO) • Money for supplies ($) • Consistency with the program, which I have control over since I have K-4 science (NP) • Will allow visual learners to soar (O) • Smaller groups to work with (SCS) • Time to collaborate and receive Professional Development (TP,PD) • Focus of elementary is literacy and math. Science is almost entirely removed with the CCSS implementation. (NP)

- Begin to offer a course in Engineering Design (PD)
- Teacher training. VERY (PD)
- Available resources to aid unit ideas as many schools do not have curriculum directors to write the curriculum ($)
- Students ability to work with others and acceptance of failure early in order to learn later (SP)
- Reducing class size (SCS)
- I have the support of the administration and promised funding. The main hurdle is to find enough time due to course load, teacher evaluation, and amount of prep time available. (TP)
- Support from other educators and experts (very) (O)
- Don't know at this point because of my lack of understanding. (PD)
- Teachers will need training. Non-multiple choice district assessments are needed. Focus needs to be on process not product. (PD,NP)
- Examples of fully functional systems in place at the high school level. (O)
- Examples/curriculum from teachers who have implemented these into their classroom (O)
- Hands on learning experience and relevant career planning (SP)
- Allocation of time to develop activities (TP)
- Nothing specific comes to mind (NO)
- High priority teacher training (PD)
- Grade level activities ($)
- Have more resources for implementation ($)
- Team teaching with science and technology teachers (as a math teacher, no time to do this). (O)
- Instead of focus on engineering, lets help the majority of our students by teaching the skills necessary to be successful in the workplace. Engineering is a career for a few students. (NO)
- It is vitally important that teachers have the appropriate resources at their disposal. This includes materials to build and design, but also resources that include lessons, or paid time to develop own units. ($,NP)

Table 15 Actions chosen by respondents as having value in implementing Engineering Design

Appendix D

Table 16

51. What is the single most important change needed to advance Implementation of Engineering Design? (n= 93)	**52 Why is the above change so important? (n= 87)**
District level support for NGSS (NP)	The focus currently is reading and math – elementary grades have cut actual science curriculum
Students need to improve their math skills (SP)	Without these basic math skills, I do not believe that Engineering Design will be a possibility within our district.
Time (TP)	Time to find/develop Engineering Design activities that would be valid in my class.
Adoption of NGSS and updated district curriculum (NGSS,NP)	Focus has not been on science, science ties in all content.
Support from colleagues and administration (NP)	If everyone supports each other, then there is a more collegial atmosphere of learning and the kids pick up on that.
Teacher In-services (PD)	I don't know much about engineering or how to teach it. I teach biology.
Professional development with Tech Ed teachers (PD)	Cross-curricular connections show the true value of the standards at all levels.
If Engineering Design is not part of a test "score" the district could care less about it. (NGSS)	DNR (Did Not Respond)
It needs to be TESTED appropriately. If it is NOT TESTED, it is not a priority from administrative standpoint. (NGSS)	It needs to become a "front burner" issue, not a back burner issue.
Time to develop activities (TP)	If time is not provided, Engineering Design will fall through the cracks.
Politicians need to support education and the sciences. There will be great cuts to education. (O)	DNR
Administrative support of science and new standards. (NP)	Without it, science is not an area of focus or concern.
Teacher professional development (PD)	Teachers gain experience and confidence in teaching Engineering Design.
Retraining and in-service (PD)	Develop the knowledge to teach the skills.
Different state/district testing requirements and an altered view of what success is in our districts, schools, and students themselves (NGSS,NP)	It is hard to change how you teach if you do not change what is deemed important. If testing stays the way it is then society, administration, government is deeming that as important. A large variable in that is getting kids comfortable in testing environments, testing technology, and questioning types… If that is how our schools' success is determined, which then reflects on funding, performance evaluations, and enrollment, that is what teachers begin to focus on whether they agree or not.
More money in education ($)	We are going to become Wississippi of the North.
More professional development (PD)	Many elementary classroom teachers do not have specialized degrees in the areas of science and math. Professional development will help them to learn about Engineering Design and how to

	implement it in Science class.
Time (TS)	We don't have enough time to teach all of our curriculum now. How are we going to add the engineering component to it?
The teacher needs to implement Engineering Design and buy into the idea. (CTA)	The teacher needs to buy into any change in curriculum in order for it to be successful.
Administrative support…both time and opportunities for in-service (NP,PD,TP)	As we all know, no meaningful change occurs without an allocation of resources. I am not an engineer, nor do I have training in engineering. In order for me to teach those concepts, I need to learn them (and not just in an "academic" sense) myself. It's the same reason many teachers struggle integrating inquiry. It's because most of them have never had experience actually conducting research. I believe engineering is much the same.
Professional development and time (PD,TS)	I am not trained in that area and I do not know how we can fit this in our already packed days.
Refocusing of mindsets and challenging fears of new ideas (CTA)	The hardest thing to do is change… for the good or bad… and for some it is extremely difficult.
Support from the top down (NP)	Support from the top down will improve community perceptions of the implementation. It would allow for greater financial support for needed materials and would make me feel better about the time invested in implementing.
Getting current teachers PD to become familiar with Engineering Design (PD)	Hard to implement changes if unsure of what it means and how to utilize it. Won't happen then.
Acceptance of NGSS standards (NGSS)	The current state standards do not have a focus on engineering.
Knowledge of what it is (PD)	Nobody that I know is even aware of it.
Understanding goals and access to materials (PD,$,NP)	There are many things that are taking priority over the science standards right now.
Teachers being more educated in the theory of teaching Engineering Design (PD)	We don't know much about it. We first must be educated ourselves to educate others.
Students willingness to persevere and try to problem solve themselves instead of relying on technology and seeing what others have done (SP)	It concerns me that so many people rely on technology to figure things out and their first instinct is to "Google" it. I think this limits people and keeps them from "thinking outside the box."
Professional Development (PD)	Knowledge of what is to be taught
Science needs to be a higher priority. Right now all focus is on reading and math. (NP)	DNR
Time (TP)	Without it the program will not be successful
Time (TP)	Need time to research and implement a new curriculum in the school.
Curriculum materials ($)	I have none. My science test is 12 years old.
Training (PD)	Build my confidence
Time and money for development of the programs. A 43 minute period is not enough time to construct your designs for a class of 30 students. (TS,$)	Students need time to work through the problems they are encountering in engineering. If you make them stop right when they are going to have a break through, it is going to cause a lot more issues for the students.
School and district support of STEM professional development (NP,PD)	Teachers cannot be successful implementing something they have no experience with.
Adoption of NGSS either at the district or state level (NP,NGSS)	It will show teachers that engineering is important and that they have "permission" to include it in their

	classroom.
Teacher understanding of what it is and how to effectively implement it in lesson plans and assessments. (PD)	DNR
School board and state adoption of NGSS (NP,NGSS)	It is difficult to argue for and have support for NGSS when it is not officially adopted.
The culture for developing Engineering Design for the district has to change. (NP)	So that teachers can implement engineering lesson with fidelity.
Teachers developing or receiving Engineering activities that align with curriculum and can be easily implemented in the classroom (PD,$)	If teachers realize how easy and rewarding the activities are, they are more likely to use in the classroom.
Districts need to make it a priority (NP)	All the emphasis is spent on reading and math right now, so science is often left out or cut out of the day.
More time would help include opportunities for students (TS)	Creative thinking, engineering cycle of build prototype, evaluate, and redesign takes a lot of time.
Leadership from district (NP)	Without district support, teachers will not implement Engineering Design
Prioritization of science as an integral part of the school curriculum (NP)	Lack of focus leads to lack of support by administration and lack of importance by teachers
The ability to see its integration with other content areas (O)	People see engineering as one more thing rather than a part of what already exists
Teacher professional development geared toward promoting successful implementation (PD)	I think most teachers don't have an idea of where/how to start implementing.
To teach engineering in a different area other than science classrooms (PD)	Our pre-service programs did virtually nothing in the area of engineering.
Understanding the importance of engineering design and know that it takes time (SP,TS)	Kids want to be done quickly. They need to know it is OK to fail, redesign, and do it again. We need time to be able to do this.
State adoption and more resources for assessments (NGSS,$)	To start from nothing is difficult to assess successfully, a curriculum or sets of assessments would make it much simpler.
Greater education about what engineering and design is and isn't, and also availability of practical examples and materials (PD,$)	It covers information for educators, both conceptual and practical.
Curriculum change. Possibly another class added that focuses on Engineering Design. (NP,O)	In our regular classes, we can maybe implement one or two projects that have a component of Engineering Design, but do not have the time to develop that skill in our students given our other standards.
Time (TS)	It takes a stretch of time to accomplish the activities.
Funding ($)	To train the teachers and buy the resources
Longer school day. Very important (TS)	95% of our school day is literacy and math instruction
Materials in classroom ($)	Money from district not pocket
I need training on the NGSS in general. Also, I need time to work on it. Honestly, with the SLO and PPG that we have to do, it is not my highest priority because of everything that is expected of me. (PD,TP)	I can't possibly do what I don't understand and I don't have time to work on.
Educating the teachers with content. (PD)	If we don't know the content, how can we teach it and make it fun?
Availability of resources for best practice ($)	The priority has never been there before, maybe only hinted at.

State adoption of NGSS and evaluation understanding (NGSS,NP,$)	Get administration and Board willing to allocate funds
In-service for us (PD)	We have little background
State-wide acceptance and allocation of sufficient funds. (NGSS,$)	Without the appropriate funds, the poorer districts will continue to lag behind.
Funding for equipment ($)	Could purchase the digital measuring devices used to measure a variety of engineering components. Could purchase building sets, K'nex, force sensors, motion sensors, etc.
Some teach a course that covers it (PD)	It's not.
Teacher training (PD)	DNR
Workshops for teachers with examples that one can take with them and use. (PD)	With all the initiatives today in schools, there is no time to develop these items on their own.
The implementation of a curriculum that has complete units with resources. ($)	As a classroom teacher who is responsible for teaching all subject areas, I do not have time or energy to write more curriculum that I am unsure of the content.
Time (TP)	The gift of time has become a forgotten treasure to the creative process of teachers involved in curriculum design.
Teacher's attitude about how they control their time. Time, time, time! It is the #1 excuse. Teachers/administrators need to start taking a hard look at how we spend our time and utilize it better. That is the ONE thing we CAN control, and yet we fall back on using not enough time as an excuse. (NP,TP,$)	Time is important because spend time and money on the things we value, so if we truly value this, we will find the time and money to implement this change.
Teacher acceptance… willingness to teach outside the norm style…. Flexibility (CTA)	In this design, not everything is scripted… teachers need to expect the unexpected and have the patience and allow kids to fail and learn/teach from it.
For educators to become familiar with the process of Engineering Design and then have the time and resources to develop Engineering Design as part of their curriculum. (PD,TP,$)	It took me a long time to figure out what the literacy standards would and should look like in my science classes. I am still working on including all of the literacy standards at least once in my curriculum. Not to design or redesign curriculum to include Engineering Design is again going to require some time.
Reduced emphasis on standardized test scores that do nothing to test a student's ability in engineering design. (NP)	I am being evaluated (judged) on how well my students do on these tests. If it is not tested, I am not likely going to teach it.
Having kids develop a foundation in math and science at lower grade levels and have students used to more open-ended activities before reaching high school. Some parents do have a problem if activities are not cut-and-dried. (SP)	This would lessen my load when teaching my lower grade-level students so that less time would be required to teach basic skills and get them used to more open-ended activities that can be accomplished/solved in more than "one correct" way.
Comprehensive professional development plan that involves understanding the WHY behind why this would benefit students (PD)	Core of how to make change
Activities for it ($)	I do not have good ideas
A change in attitudes (CTA)	Engineering Design is essential in so many job situations. The Engineering Design process can involve/be incorporated into all curricular areas!
Training of teachers on how to implement (PD)	I am not sure how much knowledge of the concepts the faculty has.

We have got to release teachers from the idea that every teacher in a PLT has to be doing the same thing. (NP)	How can I do projects that involve Engineering Design when others that I share a room with do not want to get involved?
Every cause needs a champion. A teacher in each PLT that is excited about the change would mean everything. (CTA)	People and the power of a good idea change instruction.
District priorities (NP)	Due to other things we must focus on, we have very little time to try something new in our classroom, nor do we have the class time to implement a design project
Partnering with other departments so the concepts are not perceived to be only associated with science- relevance (O)	Students, teachers, and parents need to understand the relevance of the principles of this curriculum and how they can impact the community and student careers.
Training (PD)	Teacher comfort level is directly related to use in the classroom.
We need engineering to be a part of the school district report cards. That is the only thing that matters to school administrators. (NGSS,NP)	The only focus in our district is improving math and literacy test scores. I understand the importance of those subjects, but it makes every other subject an afterthought in the eyes of administrators.
More instruction time (TS)	DNR
Stronger math and reading skills for students. (SP)	If students don't understand a problem, they can't solve it.
Buy-in from all the teaching staff. (CTA)	Consistency for all students from all teachers throughout their entire school day.
Adoption of NGSS (NGSS)	Sets a priority and standard
Aligned with NGSS (NGSS,NP)	New standards
Resources. ($)	That is how it will develop
A change in typical school culture (typical school culture meaning, "there's one right answer." "The teacher needs to be lecturing." "I do things fin… if it isn't broke, don't fix it.") (CTA)	Change won't happen if people aren't on board. There needs to be a common understanding of Engineering Design and how to be successful with Engineering Design based on each teacher's needs and personalities.
TIME (TS)	With implementation of Math Common Core, there is very little time to do Engineering within the math classroom.
More time available to teachers to plan, write, develop, and implement creative, proprietary ideas… rather than using every available moment working on SLO's, PPG's, PLC, and other acronyms related to the Teacher Effectiveness Project. (TP,NP)	The momentum is swinging away from teacher's being teachers and using their valuable time and knowledge for the students, to using their time to self-assess themselves, or work with data analysis of student progress.

Table 16 Responses for the single most important change needed to advance implementation of Engineering Design.

Afterword

Eight Practices of Science and Engineering (Appendix F, NGSS, 2013)

These eight practices of science and engineering are listed as essential in the NGSS – an essential part of every science class, K-12. The emphasis is on learning the science content while engaged in the practices of scientists and engineers; thus learning the content while developing the practice. This goes beyond previous guidelines in that students will gain more than the skill, but also the appropriate scientific and engineering knowledge for each practice. Furthermore, the science assessment will be crafted to assess student understandings of content and practices together instead of separately. Students will demonstrate their ability to investigate the natural world or solve meaningful problems through the content and the practices of science inquiry and engineering design (NGSS, 2013).

The eight essential practices of science and engineering from NGSS, Appendix F, are listed below (2013).

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

Each of these eight essential practices of science and engineering has its place within the three broad interrelated areas of Engineering Design listed below. Each of the three broad areas has age appropriate specifications within the NGSS document, Appendix I (2013).

- Define: Attend to a broad range in criteria and constraints for problems of social and global significance.
- Develop Solutions: Break a major problem into smaller problems that can be solved separately.
- Optimize Solutions: Prioritize criteria, consider trade-offs, and assess social and environmental impacts as a solution is refined.

For a further comparison of scientific inquiry and engineering design, see table 2.1 from the first part of this three-part dissertation, Faculty Preparation for Engineering Design and Next Generation Science Standards, taken from Coryn et al. (2011).