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# Challenges for Integrating Engineering into the K-12 Curriculum: Indicators of K-12 Teachers' Propensity to Adopt Innovation

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# Challenges for Integrating Engineering into the K-12 Curriculum: Indicators of K-12 Teachers' Propensity to Adopt Educational Innovations


## Abstract

With recognition of the potential expansion of the engineering pipeline, engineering was included in the Next Generation Science Standards (NGSS). The inclusion of engineering in the NGSS (and other state level STEM learning standards) comes with the expectation that K-12 teachers teach engineering as part of their curriculum. However, teacher adoption of innovations, such as teaching engineering, is a complex process that relies heavily on teacher propensity to adopt novel curricular choices and instructional approaches. Thus, prior to preparing teachers to teach engineering, there is a benefit to knowing something about how open teachers are to educational innovations and how likely they are to take the risks associated with adopting curriculum that effectively integrates unique and novel approaches to teaching and learning.

Using our experience with enhancing teacher capacity to teach integrated STEM through professional development (PD), we have recognized that the teachers who are early adopters of innovation tend to have openness to multiple ideas and engage in different STEM teaching and pedagogical practices than those who are more reluctant to consider innovations. Based on our observations, we set out to identify and empirically document the teacher perceptions for teaching engineering and indicators of a willingness to adopt innovation by using teacher created lesson plans as a source of data.

In our prior work, we have empirically documented a number of potential indicators that are associated with teacher potential to adopt innovations. Our goal for this project was to gain some foundational understanding of how teachers plan to teach engineering, and their attention to implementing other educational innovations. To achieve this goal, we analyzed a sample of 42 teacher created lesson plans drawn from a larger sample of over 300 STEM related lesson plans. We found that the teachers communicated incomplete understanding of engineering practices and design, yet created plans that shared the responsibility for assignment decisions with the students. We also found that the teachers communicated limited implementation of educational innovations in their plans. In our discussion, we propose explanation and implications for our results.

## Introduction

As new educational initiatives are introduced and gain popularity, such as teaching engineering in K-12 education, there is an expectation that teachers will learn about, embrace, and teach in alignment with the new enterprises. Yet, the teacher adoption of educational innovations is a complex and multifaceted phenomenon, typically involving the necessity to address many elements that may be unfamiliar or even uncomfortable. [1,2, 3] Given the inclusion of engineering as part of the NGSS and other state learning standards (e.g. Utah's Science with Engineering Education Standards), there is a need to monitor how engineering is being taught in K-12 education.[4] The proper engineering curriculum and instruction may be essential to assuring that when teachers engage students early in their education experience the true processes of engineering is embraced, so that they may develop accurate understandings of engineering.[5]

Using the adoption of educational innovations in general as a framework for levels to which teachers are willing to consider novel approaches to teaching engineering lessons, we examined the content of a collection of teachers' engineering lesson plans. Specifically, we coded the lessons with respect to the degree to which their plans included educational innovations,[6] the level to which students had choices in the design challenge assignments, the level to which the challenge responsibility was predetermined by the teacher or instructional resources,[3] and the inclusion of general engineering design cycle stages as outlined by Nadelson and colleagues,[3] Our goal was to determine the extent of and relationship among levels of engineering responsibility, attention to the design cycle, and inclusion of educational innovations in relationship to how K-12 teachers planned to teach engineering. Prior to discussing our methods and sharing our results, we lay a bit of groundwork for our report.

## Educational Innovations

The needs of the 21st century engineer extend far beyond expertise with applying mathematics and science to create new tools and products.[7] Engineers in the 21st century also need to be prepared to be socially and culturally aware, innovative, compassionate, ethical, life-long learners; to have a global perspective; and to be creative, and holistic thinkers responsive to the needs of society[7] and the environment. The combinations of engineering qualities, skills, and knowledge are not typically taught as part of formal K-12 education and yet the development of these perspectives and abilities forms early in student's K-12 education[8] based on their learning experiences. Thus, to address the development of 21st century engineers, K-12 education may need to embrace a wide range of educational innovations, such as teaching 21st century skills, STEM practices, and integration of family engagement.

We define educational innovations as instructional and curricular elements that have not traditionally been implemented as part of classroom practices, yet are considered to be effective for enhancing learning.[1] Thus, we maintain that instructional approaches such as place based learning, project based learning, inquiry, and curriculum integration to be educational innovations because these approaches have not been part of the traditional instructional approaches of K-12 teachers. For example, while there are expectations that science teachers may be engaging their students in inquiry activities, evidence suggests that the majority of the teachers engage their students in a level of inquiry is commensurate with essentially following scripts.[9] Thus, there is evidence to suggest inquiry as an innovation is an instructional or curricular element that is rarely fully or effectively implemented as part of teacher practice. Similarly, we consider curricular and instructional choices such as integrated STEM with the inclusion of computer science to be educational innovations, because such STEM content or curriculum are rarely taught in an integrated manner in K-12 education.

Building on our prior research on a range of educational innovations, we have defined nine educational innovations that we maintain foster student development of 21st century engineering skills, knowledge and practices (see Table 1).

Table 1

*Educational Innovations, Definitions, and Justification for Inclusion*

| Innovation | Definition | Justification |
|---|---|---|
| **Student-Centered Learning**[10] | Giving students some control over what they learn and how they learn it by allowing them to work independently. | Students who are given the opportunity to solve problems on their own are developing skills that will help them work independently in college and career. |
| **Place-Based Learning**[11, 12] | Incorporating environment and community into lessons by taking students outside of their classroom, or by making community connections inside of the classroom. | Place-based learning helps to break down the boundaries between the classroom and the world outside, thereby demonstrating to students how they can apply their knowledge in a variety of settings. Furthermore, classroom connections to the broader community help students to understand the real-world implications of the academic knowledge they are learning at school. |
| **Curriculum Integration**[13, 14] | Integrating curriculum from one content area into another. | Curriculum integration shows students how content knowledge can be applied across content areas by giving them the opportunity to use multiple content-area skillsets to complete an assignment or activity. |
| **Integration of Instructional Technology**[15, 16, 17] | Giving students the opportunities to actively use tools. | Students who learn how to use tools in order to solve problems will be better prepared to meet the technological demands of the 21st century college and career landscape. |
| **Project-Based Learning**[18,19] | Learning through conceiving of, working on, and completing a project. | Project-based learning sets students up to solve authentic problems such as those they will encounter outside of the classroom in an authentic setting. Furthermore, students work as members of teams by delegating roles and responsibilities amongst themselves, just as teams might work together to solve problems outside of school. |
| **Family Involvement**[20, 21] | Bridging the gap between home and school by including family members in lessons and assignments. | Involving families in STEM activities gives students and families the opportunity to make connections between what content learned at school and skills learned, used and valued at home. Students and families who discover and build on these connections have a valuable opportunity to scaffold content knowledge. |

| | | |
|---|---|---|
| **Inquiry**[22, 23] | Giving students the opportunity to solve genuine problems. | Teachers who give students the opportunity to answer authentic (rather than prescribed) questions which may have more than one answer are presenting a valuable opportunity for students to exercise critical thinking skills. Applying content knowledge to the solution of authentic problems presents students with a scenario that is more similar to what they will encounter in college and career than prescribed inquiry (such as book work). |
| **Core STEM Practices**[24, 25, 26] | Core STEM practices are the activities and processes that align with the authentic work and soft skill sets of scientists, mathematicians, and engineers. | Knowledge of STEM is more than learning content, it involves understanding of the practices and activities of associated with the formal process of exploration and application of STEM knowledge through practices. There are multiple overlaps in practices of different STEM professionals as well as practices that are unique to the STEM domains, combined we consider these to be core STEM practices and because of their recent emphasis – an educational innovation |
| **21st Century Skills**[27, 28, 29] | 21st century skills are the processes, activities, skills, and knowledge that are associated with the knowledge age focused society and associated expectations for students, community members, and workers | As students are prepared for the future, there is a necessity for them to gain skills such as critical thinking, creativity, collaboration, and computational thinking to effectively engage in understanding and developing the knowledge to be productive and informed with regard to learning and making decisions associated with complex situations. The acquisition of these skills may be a long term process and therefore students may need to be engaged in learning these skills early in their education and throughout their career. However, 21st century skills have not historically been explicitly taught or assessed, thus making the skills an educational innovation. |

We maintain that when teachers teach by implementing one or a combination of educational innovations, they create the context that engages students in the new age of synthesis,[30, 31] that requires authentic learning opportunities, the application and integration of STEM skills and knowledge that support learning, and lead to the development of new ideas and solutions to complex problems.

## Teacher Adoption of Educational Innovations

There is good justification for implementing educational innovations to prepare students for the workplace and societal expectations of 21st century engineers. However, because the non-traditional curriculum and instruction have not been part of K-12 teacher educational experiences, preparation, or professional expectations, there is very low likelihood that teachers have the knowledge, skills, and motivation needed to effectively implement the innovations. For example, many teachers have never taken an engineering course or been taught how to teach true processes of engineering, and therefore, lack models for how to engineering should be taught.[5] Yet with the increased awareness of engineering as part of STEM, and the expectation to teach aligned with a more integrated approach to STEM,[13] teachers are developing lesson plans for teaching students engineering with potentially constrained understanding of engineering.[32]

Given the lack of preparation of the teachers to teach engineering,[33] lack of teacher understanding about engineering,[34,35] and expectations that teachers will teach engineering, there is justification for examining how they plan to teach engineering, and how well the lesson plans they generate align with the standards and expectations of K-12 educators.

**How K-12 Teachers Teach Engineering**

The work by Nadelson and colleagues[3] found that when elementary teachers designed and implemented engineering lessons, they tended to deviate from the design cycle. For example, instead of developing prototypes that provided solutions to problems, the teacher generated engineering lessons evolved to a focus on building models of processes (e.g., the sprouting of a seed) or tinkering to make a product, without documentation, testing, evaluation, or redesign as part of the process. While students were engaged in these activities, many of the lessons were not aligned with basic engineering principles and design, but did involve hands-on building of a product or tool in response to provided criteria. However, the notion that engaging students in hands-on activities to build something as engineering reflects a limited understanding of true engineering design.[36] The research of Nadelson et al.[3] suggests that while teachers may be attempting to engage their students in engineering, their perceptions and ideas of what constitutes engineering may be limited, leading to lessons that are not aligned with what engineering educators would consider to be engineering. Hence there is value to examining the level to which teacher designed lessons do attend to the common expectations for engineering lessons.

There are multiple frameworks for the design cycle and wide variation in the expected stages of design. In an attempt to bring some clarity and consistency when examining teacher practice Nadelson and colleagues[3] identified the essential design cycle elements and provided definitions for each stage of the cycle (see Table 2). The design framework is useful for examining teacher practice and student engagement in the design cycle. Further, the framework provides a means of examining teacher developed lesson plans for attention to the essential design elements. The consideration of the lesson plans using the framework provides an opportunity to gain insight into what teachers may perceive as engineering and their effective adoption of engineering as an educational innovation.

**Table 2**

*Essential Elements of the Engineering Design Cycle*

| | Problem Statement | Criteria and Constraints | Generate Ideas and Select Solution | Process Used to Build the Product | Present Results and Evaluate |
|---|---|---|---|---|---|
| Description of the Associated Process(s) | The problem to be solved is identified and explained | Criteria to which the solution must conform, and the specifications for the product are listed<br><br>The constraints, limitations, or bounds | Brainstorming about possible solutions to the problem<br><br>Identifying what seems to be the best solution | The solution is prototyped<br><br>A solution is selected<br><br>A working solution is created | The final solution is presented to others<br><br>The solution is evaluated for conformity to criteria and constraints and effectiveness in solving the problem |

| | | | | |
|---|---|---|---|---|
| | for the product are recognized | Justification and assurance that the preferred solution conforms to criteria and constraints | The solution is tested, data are gathered | Evaluation is used to plan for the next generation of the solution |

In addition to the framework for engineering design elements, we also considered the level of engineering rubric developed by Nadelson et al.(see Figure 1).[3] The rubric is used to determine the level of responsibility that students have for the stages of an engineering design activity compared to the level assumed by the teacher (or instructional materials). The range of outcome for the rubric is from 0 to 5. Scores near 0 indicate that the student has little responsibility for determining the process of the design element, as the design elements is being directed by the teacher or instructional materials. In contrast, scores near 5 would indicate that students have great or complete responsibility for the design elements. Values near 2.5 (the center of the spectrum of engineering design responsibility) would indicate shared responsibility. We maintain that a score using the rubric to evaluate teacher lesson plans provides a metric for how comfortable teachers may be teaching engineering. We posit that lessons plans that reflect higher levels of student responsibility would indicate that teachers have higher levels of comfort teaching engineering and therefore, are capable of guiding students rather than directing their engagement.

| Structure Responsibility Score 0 to 1 [If teacher or resources solely responsible—Score 0] [If student is solely responsible—Score 1] | Design Element | | | | | Level of Design Sum of Element Scores (From 0–5) |
|---|---|---|---|---|---|---|
| | Problem Statement | Criteria and Constraints | Generate Ideas and Select Solution | Process Used to Build the Product | Present Results and Evaluate | |
| Responsibility for Element Structure Score (from 0 - 1) | | | | | | |

Figure 1. The Level of Design Rubric.

## Method

To answer our overarching research question, "What are the indicators of K-12 teachers' propensity to adopt educational innovations and the relationship to their plans for teaching engineering?" we developed a series of guiding research questions:

- *How aligned are teacher-developed engineering lesson plans with the engineering design cycle?*
- *In teacher-developed engineering lesson plans, who is doing the engineering?*
- *What other educational innovations are present and how are the innovations represented in the teacher-developed engineering lesson plans?*
- *It there a relationship between the alignment of teacher-developed engineering lesson plans and their inclusion of educational innovations?*

## Data Source

The source of our data were engineering-focused lesson plans developed by the K-12 teachers who attended a summer week-long integrated STEM professional development (PD) institute. Details of the professional development have been reported previously.[24, 37] The lesson plans were part of the activities that participants completed in order to fulfill the requirements for the PD associated college level continuing education credits. All teachers attending the PD were expected to develop an integrated STEM lesson plan, but the focus could vary. We provided the teachers with a template for their lesson development that included prompts to assure they fulfilled the expectations for communicating the associated lesson plan learning standards, expected lesson outcomes, 21st century skills students would engage in, integrated lesson activities, necessary instructional materials, and a plan for assessing student learning.

The lesson plans have been de-identified, grouped by the course attended at the PD, uploaded to the Google Site, and made publically available. The lesson plans that we considered in our analysis were those created by teachers who contributed the "Lego Robotics" collection, the "Robotic Reaching NGSS and CCSS- M 1st" collection, and the "Engineering for Sustainability" collection. While there may not have been an explicit expectation of the teachers who attended these three courses to develop lesson plans focused on engineering, the association did seem likely as the courses focused extensively on engineering processes and principles. We were able to identify 42 engineering design focused lessons for analysis. The collection of lessons can be found here: https://sites.google.com/a/boisestate.edu/i-stem-2014-lesson-plans/

## Analysis

We used two previously developed lesson plan evaluation tools. The first was a tool developed by Nadelson et al. [3] which is used to evaluate the level of teacher and student engagement in the engineering lesson (see Figure 1). Using the five design element framework created by Nadelson et al.[3] (see Table 2) we examined each lesson plan to determine the number of design elements present, as well as which elements were present.

The third tool we used in our analysis was the set of rubrics developed by Sias et al., [6] to examine the level to which educational innovations are communicated in teacher-designed lesson plans. For each of the nine innovations, the authors created a rubric to rate the presence of each innovation using five-point scoring scales ranging from the practices being completely absent to the practice being fully implemented. For example, the integration of instructional technology into the lesson plan the scoring scale ranged from *No Technology* (1) to *Essential to Complete the Lesson* (5). To guide their rubric development for some innovations they considered the extant tools or models (e.g., Schwab and Brandwein's[38] level of inquiry framework). They adapted and adopted these frameworks to effectively structure their rubrics for evaluating teacher generated lesson plans.

## Results

***Level of responsibility***. Our first research question asked: *In teacher-developed engineering lesson plans, who is doing the engineering?* To answer this question we examined the lesson plans using Nadelson et al. [3] level of engineering design rubric. In our analysis we found that the teachers tended to develop fairly student-centered engineering lessons, with limited direction from the teacher or instructional materials. The overall average rating of the lessons was 2.49; essentially equal levels of teacher and student responsibility for the design element decision-making in the engineering lesson plans.

***Alignment with the design cycle.*** Our second research question asked: *How aligned are teacher-developed engineering lesson plans with the engineering design cycle?* To answer this question, we examined the lessons for the presence of each of the five design elements presented in Table 2. We found limited to no alignment between the design cycle stages in many of the lesson plans. Many of the lesson plans involved building models and making the model work (e.g. make a model bird), and therefore, did not attend to any of the design cycle elements in their lesson plan (38%). None of the 42 lesson plans we evaluated attended to all 5 stages of the engineering design cycle (see Figure 2). The lessons commonly were missing idea generation, with only 20% of those that included at least one design element including the idea generation. Absent in the lesson plans (0%) were the design elements of identifying the criteria and constraints and generating a problem statement (see Figure 3).

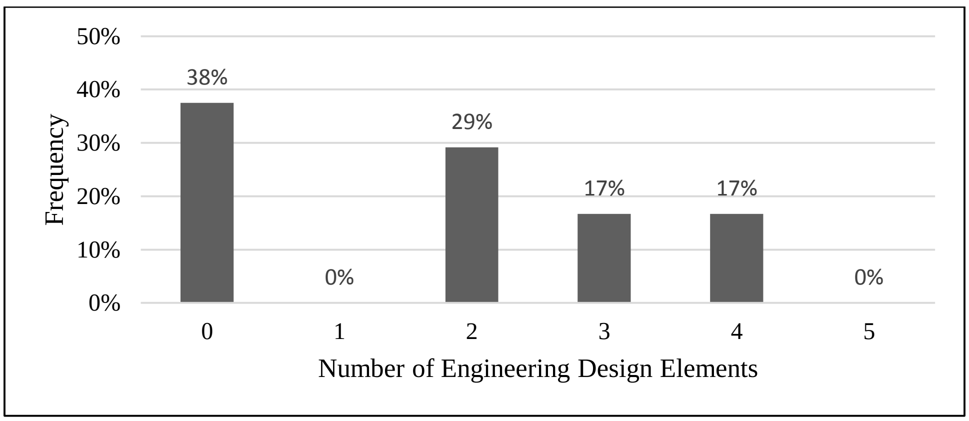


*Figure 2.* The frequency of design cycle elements present in lesson plans.

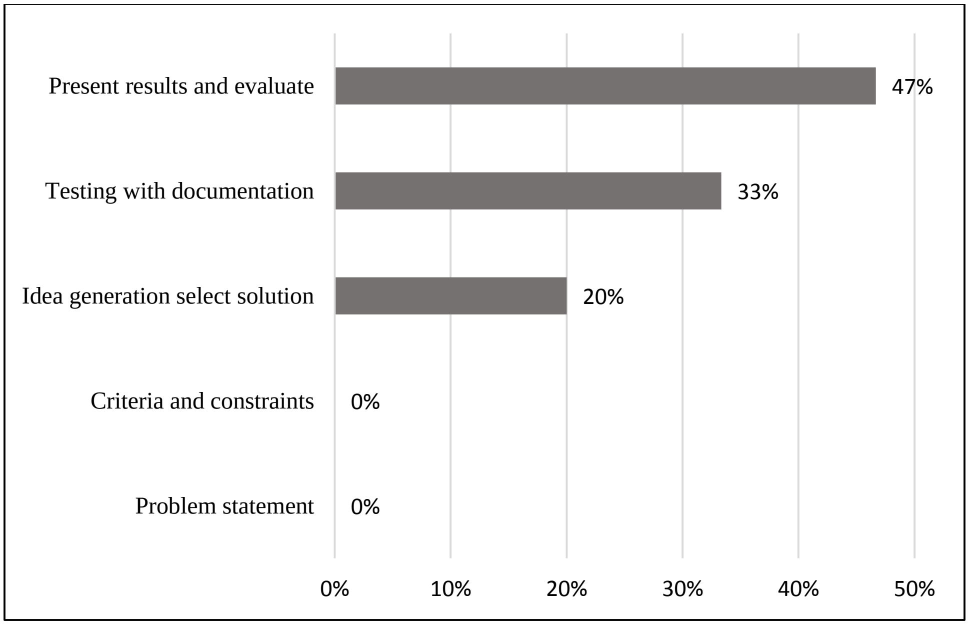


*Figure 3*. The frequency of inclusion of the design elements in the lesson plans.

***Educational innovations***. Our third research question asked: *What other educational innovations are present and how are the innovations represented in the teacher-developed engineering lesson plans?* To answer this question we examined and scored the lesson plans according to the Sias et al. [6] lesson plan educational innovation analysis tool. Similar to the number of design elements addressed, we found variation in the level to which the teachers' lesson plans addressed several educational innovations (see Figure 4). In some of the lesson plans, the teachers did not communicate actions or activities that involved various educational innovations, taking a traditional approach, while other educational innovations were included to varying degrees.

In our analysis of level of student-centered learning, our results indicated the lesson plans were primarily teacher-focused, the 21$^{st}$ century skills limited in inclusion of curriculum integration, inquiry and project-based learning, and core STEM practices were applied very little in the lesson plans, indicating that these three educational innovations were marginally attended to in the lesson plans (see Figure 4). Many of the innovations were normally distributed with the majority of lessons plans somewhere between no integration to complete integration; such as with curriculum integration, level of inquiry, and project based learning. The use of instructional technology as a tool to solve problems as an innovation was substantially embraced, indicating that the teachers included technology use to a high degree in their lesson plans.

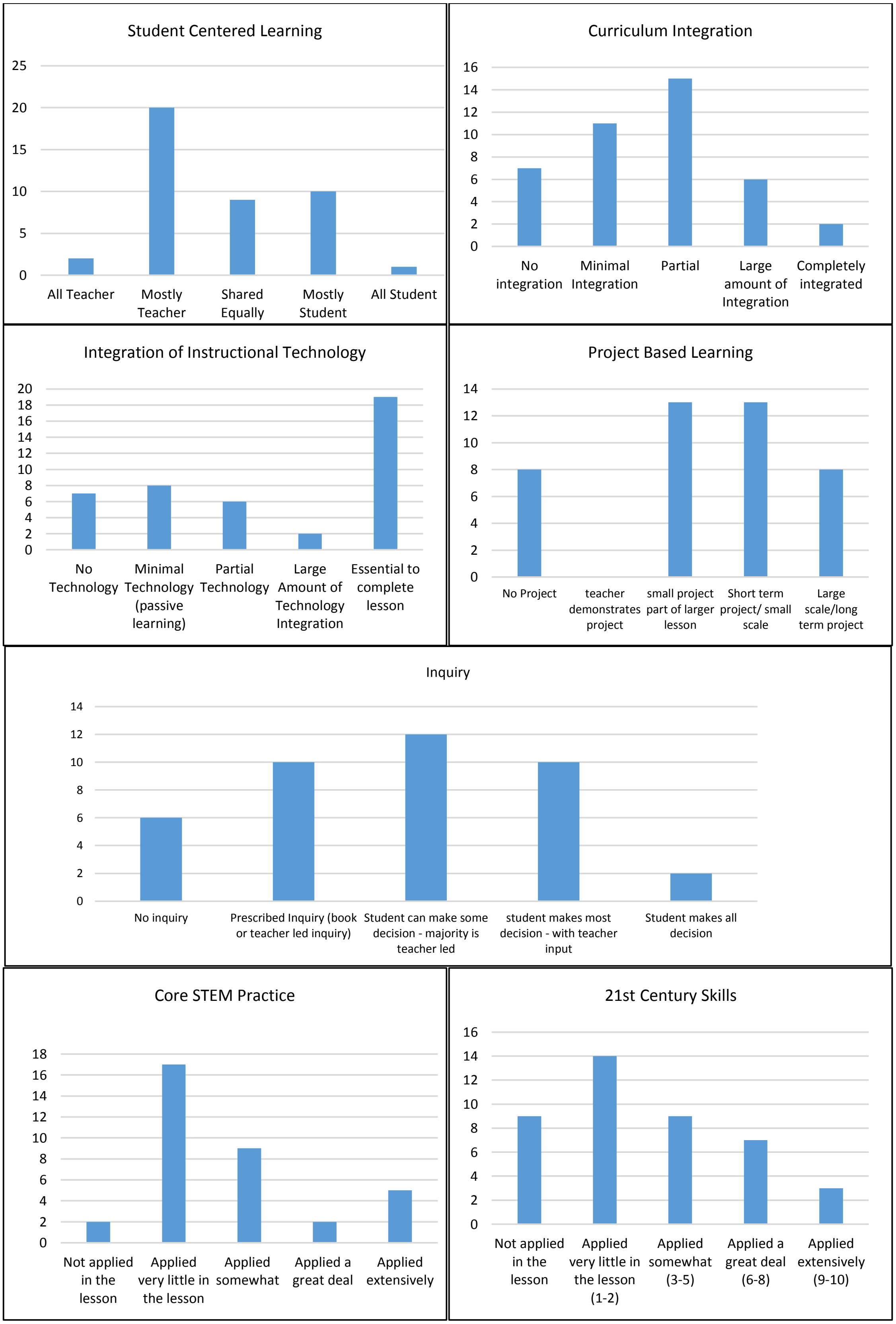


*Figure 4*. Levels of educational innovation addressed in the lesson plans

Our fourth research question asked: *It there a relationship between the alignment of teacher-developed engineering lesson plans and their inclusion of educational innovations?* To answer this question, we examined the outcome of the engineering design cycle elements and the levels of included educational innovations. We found that the communicated level of educational innovation integration in the lesson plans (see Figure 4) paralleled the level of design responsibility and the inclusion of engineering design stages in the lesson plans (see Figure 2). Similar to the results of our analysis of design elements and level of responsibility for the elements of the assignments, the implementation of educational innovations tended to focus on the balance between teacher focus and student focus. Our results suggest that student centered learning and attention to core STEM practices are likely indicators of the nature of engineering lesson planning and the level of teacher responsibility for the engineering design process.

**Discussion and Implications**

Given the inclusion of the teaching of engineering in the K-12 curriculum as motivated by the NGSS or similar State learning standards, K-12 teacher knowledge and teaching of engineering is now an expectation and necessity for these educators to effectively meet the goals of the framework and implement the new standards. Thus, there is value in knowing how teachers might plan to teach engineering concepts, the concepts to be taught, and the level to which students are expected to be responsible for the engineering process. Considering teachers' lesson plans as an artifact that effectively reflects their instructional and curricular choices, we examined a collection of teacher-generated lesson plans for indicators of engineering design instruction to gain insight into how the teachers might plan to teach true engineering concepts. We also examined the lesson plans for indicators of implementing educational innovations as potential indicators of teacher preparation and approach to teaching engineering lessons.

Our finding that the level of engineering responsibility was overall equally shared by the teachers (or resources) and the students suggests that the teachers had some comfort with allowing their students to make choices in their assignments. However, when examined with the degree to which the stages of the engineering design process were addressed in the lesson plans, the results suggest that it is likely that the teachers have a constrained view of engineering. Thus, the responsibility may be a perception that hands-on activities (including making models) aligns with teaching engineering. It may also be possible that the as the teachers' developed their lesson plans they did not consider engineering as the primary focus of the lesson (although the participants did attend courses when the emphasis was on engineering) as many of the lessons focused on model making. The implications for these findings suggests that teachers are in need of more explicit professional development on the engineering design cycle, how to teach the cycle, and provided with models of effective engineering lesson implementation.

The alignment between the inclusion of educational innovations in the lessons and engineering design implementation suggests that there is likely a similar lack of awareness or experience with effective models of implementing educational innovation. As with engineering design, it is likely that few teachers have been prepared to effectively implement educational innovations and have few models for reference for how to integrate the innovations as part of their curricular and instructional choices. Thus, similar to the implication of our engineering design findings, we maintain that teachers are likely in need of professional development that explicitly address how to implement educational innovations, models for effective implementation, and exposure to the benefits to student learning that the educational innovations afford.

## Limitations

The first limitation of our research is the relatively small number of lesson plans that we examined as part of our research. While limited, these lesson plans were submitted after a 45-hour, week-long integrated STEM professional development program. Thus, while limited, the lessons are likely representative of the engineering lesson plans of K-12 teachers. Both a larger sample of lesson plans and longitudinal studies of teacher lesson plan development may provide insight into how the lesson plans communicated knowledge and ideas for teaching engineering design and educational innovations.

The second limitation is the examination of the lesson plans without verifying the intention of the plans by the teachers. However, given the expectation that the lesson plans were to be posted online so that they could be accessed by the greater community, it is likely that teachers created the lessons understanding that other teachers would (or could) use them. In future research, we will gather additional data by interviewing the teachers about their lesson plans and how they would implement the lessons as well as their knowledge and experience teaching engineering and educational innovation.

## Conclusion

Developing the pathways for future engineers begins early in education by engaging young learners in true engineering activities. Thus, K-12 teacher perceptions and implementations of engineering lessons is critical to the preparation pathways of engineers. Teacher lesson plans provide insight into how teachers might teach engineering lessons and implement related educational innovations. Our research revealed that teacher lesson plans communicate constrained knowledge of engineering design and limited attention toward educational innovations. Our results indicate more work needs to be done to prepare teachers to teach engineering and effective engage in implementing educational innovations.

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