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Examining and Characterizing Elementary School Teachers' Engineering Design-based Instructional Practices and Their Impact on Students' Science Achievement

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Introduction

Over the past ten years, considerable attention has been given to introducing K-12 students to engineering concepts and practices. This is most evident in the National Research Council's *Framework for K-12 Science* Education [1] and the recent introduction and adoption of the *Next Generation Science* Standards [2]. A signature component of these documents is the introduction of scientific and engineering practices. The use of "practices" signifies the importance of learning, applying, and transferring knowledge and skills simultaneously in a manner reflective of the work of scientists and engineers. For teachers, knowledge and practice are interconnected when designing and implementing meaningful science learning experiences for K-12 students, and the instructional practices teachers employ are critically important to facilitate and support K-12 students' learning of science through engineering. To date, however, little evidence has been produced about elementary teachers' engineering instructional practices and their impact on student science achievement.

Using the theoretical lens of situated learning [3], researchers in this study examined how learners (elementary teachers and students) became part of a community of practice focused on engineering design in elementary science in which they learned from others and advanced to become full-fledged participants of the community. The context of this study was a large, university-school science partnership aimed at improving elementary/intermediate school (defined here as grades 3-6) students' learning of science through engineering design. In this study, we examined the instructional practices elementary school teachers engaged in when they introduced students to selected engineering design tasks and the impact these practices had on student achievement. In a prior study [4], the authors were able to identify a broad relationship between grade 5 and 6 teachers' instructional practices when implementing engineering design-based activities in the elementary classroom and their students' learning outcomes. This study replicates the previous study with a sample of grade 4 teachers, students, and design activities, and seeks to extend the previous work by determining whether specific teacher practices are related to student learning. By critically examining how elementary school teachers' instructional attempts at integrating engineering design-based science instruction influence student achievement, we aim to narrow the gap between teacher practice and student learning of science and engineering in the elementary classroom.

Research questions

This study was guided by the following research questions: a) what instructional practices do elementary school teachers employ when implementing engineering design-based science instruction? b) How do students perform on assessments of content learning after participation in engineering design-based science instruction? and c) To what extent do teachers' specific instructional practices correlate with students' learning from engineering design-based instruction?

Theoretical framework

We employed the construct of situated learning as our theoretical lens for this study. According to Lave and Wenger [3], learning occurs "in situ" or "learning by doing," both in formal classroom settings and in informal settings. This theoretical perspective views knowledge construction as arising conceptually through the dynamic construction, re-construction, and interpretation within a social context. Furthermore, knowledge is socially reproduced and learning takes place through participation in meaningful activities that are part of a community of practice [3], participation that is mutually constituted through and reflects our thinking and discourse skills [5].

In this study, both teacher and student participants learned as active members of the school-university math and science partnership. Participation in communities of practice has been found to be beneficial for both teacher and student learning [6], [7]. In this study, teachers participated in multi-day, intensive summer professional development where they were immersed in authentic, standards- and engineering design-based tasks facilitated by university STEM faculty. The tasks included design experiences focused on real-world problems that teachers then translated into their own practice. Teachers developed their practice by employing instructional strategies, classroom organizational structures, and a cognitively appropriate engineering design model that mirrors the work of professional engineers and engineering educators. By co-participating in the professional development, and through fruitful collaborations with more knowledgeable members of the community [8], teachers collectively developed an understanding of what design entails and how to translate this propositional knowledge into practice. As a result, students in the teachers' classrooms learned how to engage in engineering practices, gradually developing knowledge of how to identify essential features of a design problem, gather information that informs the problem, plan, construct, test, evaluate, and optimize a design solution. In this manner, teachers and students, over time, became active, legitimate participants of the community of practice, generating new knowledge of both science and engineering core ideas, crosscutting concepts, and related skills.

Context of the Study

The context of this study was a large, multi-year university school partnership that included the participation of over 200 elementary/intermediate school teachers, 5,000 students, 25 STEM faculty and educational researchers. Science Learning through Engineering Design (SLED) is an NSF-funded partnership project aimed at improving elementary school (grades 3-6) students' learning of science and math through: 1) development and implementation of a set of standards-based, inquiry-oriented, and engineering design-based curricular resources for teaching elementary science; and 2) a comprehensive, content-rich, teacher professional development program. Purdue University is the lead entity of the partnership, which began with four partner school districts in the state of Indiana and has now expanded to include teachers from more than 35 school districts throughout the state. The study reported herein utilized data from the project's fourth cohort of teachers that implemented engineering design-based activities in classrooms during the 2014-15 school year.

Participants of the study

For this study, a strategic sample of four individual cases (four grade 4 teachers and 93 students) was purposefully selected from the larger population [9]. These cases represented individual classroom teachers and their students who provided consent (both teacher and student), completed all research-related activities, and implemented fully the same two engineering design-based science tasks during one academic year. The teacher participants included three females and one male from three different elementary schools in one participating suburban school district. All were White, Caucasian with a range from 7 years to 25 years of teaching experience. See Table 1. The demographics of the entire sample of student participants included the following: 37 females, 53 males, and 3 other/not reported; 59 White/Caucasian (63%), 10 Hispanic or Latino (11%), 3 Black or African American (3%), 1 Asian (1%), 12 (13%) reporting more than one race/ethnicity, and 6 (6%) other/not reported. See Table 2.

Table 1. Demographic profile of teacher participants

Teacher*	**School***	**Number of years teaching**				**Year in the Partnership**
		5 to 10	11 to 15	16 to 20	21 +	
Harold Art	Warren Elementary	x				2
Molly Anderson	Kennedy Elementary	x				2
Opal Carter	Ridge Elementary			x		2
Pam Les	Ridge Elementary				x	1

*Pseudonyms are used to protect the anonymity of the participants and their respective school settings.

Table 2. Demographic profile of student participants

Teacher [Pseudonym]	**# of Students**	**Male**	**Female**	**Other / Not Reported**	**Hispanic or Latino**	**Black or African American**	**Asian**	**White Caucasian**	**More than 1 Race / Ethnicity**	**Other / Not Reported**
Harold Art	23	15	8	0	1	0	0	18	3	1
Molly Anderson	26	14	12	0	4	1	1	14	4	2
Opal Carter	21	11	8	2	3	0	0	12	2	2
Pam Lee	23	13	9	1	2	2	0	15	3	1

Design tasks

The project's curricular materials include a set of grade-appropriate, standards-based, engineering design-based tasks that utilize and/or reinforce one or more key science concepts. Curricular materials were developed by multi-disciplinary design teams, consisting of university STEM faculty who were recruited to participate in the project and worked in a community of practice with classroom teachers to create standards-based, age-appropriate materials [8]. Each design team carefully and critically examined the standards and developed, field tested, and revised the engineering design-based science lessons. Each design task was developed to include essential features including: (a) a client-driven and goal-oriented orientation; (b) an authentic context; (c) the presence of constraints; (d) cooperation and teamwork; (e) student creation of an artifact or process as a solution; (f) more than one possible solution; and (g) use of materials and tools familiar to students [10]. To date, more than thirty grade-appropriate, classroom-tested design tasks have been developed by the SLED project; a complete list is available on the project's website (https://stemedhub.org/groups/sled/design_resources). See Table 3 for the two specific design tasks that were the focus of this study.

Table 3. Grade 4 study design tasks.

Grade Level	Task	Description	Core science concepts
4	Door Alarm [11]	Design a door alarm that sounds when someone open the door to the room.	electricity, current, electric circuit
4	Slow Boat [12]	Design attachments to a boat to make it move more slowly through the water.	forces, motion, drag

Each design task was the anchor for a unit of science instruction focused on core, standard-based concepts that included electricity and electric circuits for Door Alarm [11] and motion and forces (specifically drag) in the case of Slow Boat [12]. Each task could be viewed as a competition in which student design teams competed, not with each other, but to meet the design specifications (i.e. client's needs, goals, and constraints). A design goal such as, "Can you devise a way to make a boat move more slowly through the water?" provides a challenge, dares the students to test their skills and their knowledge to see if they can design a prototype that fulfills all the requirements. Accompanying each challenge are wrap-around exercises – including science inquiry activities, concept-mapping, journaling through the use of "design notebooks," and oral reporting – designed to help students construct their personal meanings.

Data collection and analysis

The research team employed a mixed methods approach, collecting quantitative and qualitative data concurrently throughout the course of the study [13] (see Table 4).

Table 4. Overview of data collection methods

Research questions	Data collection methods	
	Qualitative	*Quantitative*
What instructional practices do elementary school teachers employ when implementing engineering design-based science instruction?	Interviews Classroom Observations	SLED Engineering Design-based Classroom Observational Rubric
How do students perform on assessments of content learning after participation in engineering design-based science instruction?		Pre-/post- Knowledge Tests
To what extent do teachers' specific instructional practices correlate with students' learning from engineering design-based instruction?		SLED Engineering Design-based Classroom Observational Rubric Pre-/post- Knowledge Tests

Teacher participant data

Classroom observations. Observational data were used for capturing a comprehensive description of each classroom setting, teachers' instructional moves, students' engagement in design, and the meanings of what was observed from the perspective of the teacher participants. Members of the research team conducted formal classroom observations of each teacher's classroom using a schema of validated observation codes for engineering design-based science instruction [14]. This included the first to last day of implementation of each design experience. On average, teachers spent approximately six 45-minute classroom sessions implementing each design task (~ 4.5 hours/ each design implementation; total = 9 hours/teacher). Observers strategically maintained a running log of a teacher's instructional moves, including but not limited to, asking and answering questions, facilitating whole class discussions, giving directions, and modeling effective design-related skills such as note-booking, sketching, and communicating. Observation data were independently coded and the codes were then compared for agreement. Inter-rater reliability for the observers in this study yielded an inter-reliability of 0.84 for the observation protocol.

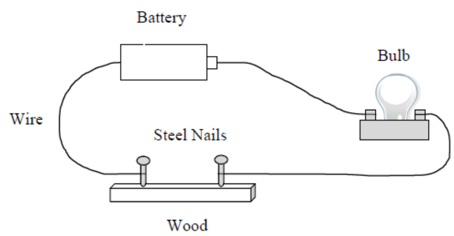
To align the coded classroom observation data with national reform documents, members of the research team developed an analytical rubric consisting of ten major categories representing the following: (a) a specific phase within the engineering design process and (b) one or more NGSS engineering practices (See Appendix A) [15]. Each category within the rubric consists of five levels of performance with a 0-, 1-, 2-, 3-, and 4- point value. Four denotes the highest fidelity to the project's model and NGSS practices for engineering design-based instruction (very descriptive), whereas 0 denotes the lowest, indicating no evidence or occurrence. The mean of each category rather than the total score was reported in order to highlight the findings. Therefore, a 3 or higher was indicative of engineering design-based teaching. A teacher with a high degree of fidelity to the project's model and NGSS practices would obtain a mean score of 3 or higher, while a teacher with a low degree of fidelity would obtain a score of 2 or lower.

Interviews. A series of two semi-structured interviews were conducted for each teacher participant. Teachers participated in one interview early in the school year prior to implementation and a second interview after implementation. Interviews conducted prior to implementation were designed to uncover teachers' conceptions about engineering design, expectations for implementing engineering design tasks, and how students learn science through design. Interviews conducted at the end of the school focused on teachers' reflections on implementing design, challenges, and evidence of student learning. A total of eight 45-minute interviews were recorded and transcribed by members of the research team. Preliminary analysis of interview data entailed the use of open coding where categories were tentatively identified then later revisited to form multi-dimensional categories [16]. Similar words or phrases used by the teacher participants were grouped into comparable categories and these categories were eventually modified, replaced or merged together to form manageable chunks. Reading and re-reading of the data allowed researchers to identifying emerging themes. These themes were then utilized to confirm or refute patterns found in the observation data.

Student participant data

Students' development of content knowledge was assessed using identical pre- and post-instruction tests. Developed by the project team, the content tests were composed of multiple-choice items that were designed to measure different levels of comprehension (low, medium, and high cognitive demand) using items that addressed both science and engineering content. Each test focused on the specific science and engineering content that was addressed in the corresponding unit design task. Example items from each of the two task tests are shown in Figure 1. Tests were analyzed for item validity, and an overall Cronbach alpha reliability was calculated based on the post-test administration of the test. The Door Alarm test consisted of 12 items (9 science and 3 engineering), and it had a Cronbach alpha reliability of 0.76. The Slow Boat test also consisted of 12 items (9 science and 3 engineering), and it had a Cronbach alpha reliability of 0.69.

A student set up the electrical circuit shown below. The bulb did not light. What can the student do to make the bulb light?



A. Add a second battery to the first battery.
B. Replace the wires with thicker wires.
C. Replace the steel nails with aluminum nails.
D. Connect the steel nails with a piece of wire.

When would a person feel the largest drag force?

A. Walking on a dry sidewalk.
B. Walking on a wet sidewalk.
C. Walking through a wading pool full of water.
D. Walking through dry leaves on the ground.

Which of the statements below ***best*** describes a characteristic of the engineering design process?

A. The design solution will be better if one person works on it by themselves.
B. There can be more than one design solution that will solve a problem.
C. The end user and client will be the same people.
D. Engineers should decide what problem needs to be solved, not the client.

Figure 1. Sample Student Knowledge Test Items for Door Alarm and Slow Boat Tasks

The pre-instruction knowledge tests were administered at the beginning of the school year, and the post-instruction knowledge tests were administered within two weeks of the completion of the corresponding design task in the participating classrooms. Basic descriptive statistics were calculated for each test for the overall sample and by classroom. To determine if students showed statistically significant knowledge gains from pre-test to post-test, paired sample t-tests were used to compare the post-test to the pre-test means within and across teachers. To assess whether there was a relationship between the teachers' implementation of the design-based lessons and student performance on the knowledge tests, Pearson product moment correlations were calculated between teachers' observational rubric scores and two measures of learning, students' scores on the corresponding post-test and their pre-test to post-test gains. All statistical analyses were conducted using SAS 9.4 (SAS Institute, Inc.).

Triangulation

To determine internal validity of our findings, the research team utilized multiple data sources to employ what is referred to as triangulation [13]. The research team started the process with a preliminary analysis of both classroom observations and teacher interviews. Researchers then conducted an analysis of the student knowledge assessments for each classroom teacher. The research team then sorted and organized each data set according to each classroom teacher. Utilizing teachers' scores on the observation analytical rubric, the research team compared these results with student performance on knowledge assessments to determine if the teachers' instructional moves aligned with how students performed on the assessments. Interview data were then used to corroborate evidence and verify and validate assertions.

Results and Discussion

Teachers' Enacted Attempts at Engineering Design-Based Instruction

Table 5 shows a breakdown of the mean scores for the ten key elements within the rubric for the four teachers' implementations of the two design tasks. The overall mean score or rating for the teachers' implementation of the Door Alarm task ranged from a low of 1.60 (Pam) to a high of 3.30 (Molly). A rating of 2 or less indicates relatively low fidelity of implementation with desired practices for engineering design-based science instruction. Thus, the mean score for Pam (1.60) represents relatively low fidelity of implementation, while the mean score for Harold (2.50) and Opal (2.50) indicates moderate fidelity of implementation, and the mean score for Molly (3.30) indicates relatively high fidelity of implementation. The overall mean scores for the teachers' implementation of the Slow Boat task were higher across the board, ranging from a low of 2.60 (Pam) to a high of 3.60 (Molly). In this case, the mean score for Pam (2.60) represents moderate fidelity of implementation, while the mean scores for the other three teachers – Opal (3.00), Harold (3.20), and Molly (3.60) – indicate relatively high fidelity of implementation.

Interview data indicated that Pam's low to moderate fidelity of implementation was due to her inexperience with teaching engineering design-based science instruction. In her second interview Pam stated:

> Considering this was my first time teaching these tasks, I thought my students and I did okay. Door Alarm was more difficult for me. I didn't give students enough time for planning and I could tell during testing that they weren't able to get the alarm to sound. I don't even think I helped students facilitate an analysis of their designs…Slow Boat was much more manageable for me…I think it's because they were able to conduct fair tests of their designs. Having data from all the boats was good for them to see how their design performed relative to others (Interview #2).

Classroom observation ratings were higher overall for the implementation of Slow Boat compared to Door Alarm. Interview data suggested that the teachers were allocating more time during different design phases in Slow Boat versus Door Alarm. Molly admitted: "I learned a lot from doing Door Alarm and decided to have students work together on spending more time during constructing and testing of their model boats" (Interview #2). Harold stated that he:

> …devoted extra time for students to sketch and share plans and also collaborate on analyzing test results as a whole class during Slow Boat because I thought they needed more time than in Door Alarm where their designs did not require a lot of testing (Interview #2).

Opal claimed that for Slow Boat "the task called for students to spend more time in testing, gathering data, and interpreting their findings" (Interview #2). These results may be indicative of increasing teacher experience in recognizing different aspects of the engineering design process, which would support the notion that teachers were becoming more proficient members of the community of practice over time.

Table 5. Mean Scores from the Engineering Design-based Classroom Observational Rubric for Teachers (n = 4 teachers)

Key Element		**Mean Score** ***Door Alarm Task***					**Mean Score** ***Slow Boat Task***				
		Harold	Molly	Opal	Pam	Average	Harold	Molly	Opal	Pam	Average
1	Ask questions and define features of an engineering problem (i.e., criteria, constraints, goal, end user, client and client's needs)	2.00	4.00	3.00	1.00	2.50	3.00	4.00	2.00	2.00	2.75
2	Express individual ideas in writing using models or drawings.	2.00	3.00	3.00	2.00	2.50	3.00	3.00	3.00	2.00	2.75
3	Share individual ideas orally and express group ideas in writing.	2.00	3.00	3.00	2.00	2.50	3.00	3.00	2.00	2.00	2.50
4	Collaborate with one or more peers throughout the design process for the selection of the most promising solution.	3.00	3.00	3.00	2.00	2.75	4.00	3.00	3.00	3.00	3.25
5	Use of and access to a range of tools and manipulatives to construct and test a promising solution.	4.00	4.00	3.00	2.00	3.25	3.00	4.00	4.00	2.00	3.25
6	Collaboratively develop a model using an analogy, example, or abstract representation to describe a design solution that aligns with essential features of the engineering problem.	3.00	3.00	2.00	2.00	2.50	4.00	4.00	2.00	2.00	3.00
7	Test proposed solution of a design. Use data and scientific concepts to evaluate and refine design solutions.	2.00	2.00	2.00	1.00	1.75	4.00	4.00	4.00	3.00	3.75
8	Communicate clearly and persuasively the ideas, final design solutions, and related performance results using relevant evidence about how it meets the criteria and constraints of the problem.	3.00	4.00	2.00	1.00	2.50	3.00	4.00	4.00	3.00	3.50
9	Compare performance results, revise, and improve designs.	2.00	4.00	2.00	2.00	2.50	3.00	4.00	4.00	4.00	3.75
10	Teacher as facilitator	2.00	3.00	2.00	1.00	2.00	2.00	3.00	2.00	3.00	2.50
Overall mean		**2.50**	**3.30**	**2.50**	**1.60**	**2.48**	**3.20**	**3.60**	**3.00**	**2.60**	**3.10**

The differences in ratings across tasks may also be attributable to differences in the nature of design tasks themselves. For example, the Slow Boat task is one that lends itself particularly well to testing and redesign. Students design ways to increase drag to slow down their boat, they are able to test their boat adaptations in a water tank, and then make design changes to try to make the boat move even slower. In the Door Alarm task students test their design to see if it makes a closed circuit that sounds an alarm when a door is opened. In contrast to the Slow Boat task, this task yields a more absolute or finite solution and is less open-ended when it comes to testing and redesign. Designs are either successful in sounding the alarm or they are not, and there is less opportunity for repeated testing and redesign. This may be a factor in the lower scores on rubric elements 7 and 9 for the Door Alarm task compared to the Slow Boat task.

Assessment of Students' Content Knowledge

Tables 6 and 7 show a breakdown of the students' mean scores on the pre- and post-knowledge tests for the two engineering design activities that were implemented. Table 6 shows the knowledge test results for the Door Alarm task. Across all four teachers, on average, students scored 5.97 (about 50%) on the pre-test and 9.64 (about 80%) on the post-test, a gain of 3.67 points (about 30%). This gain was statistically significant ($t = 13.48$, $p < .0001$), which suggests that the grade 4 students developed their understanding of content knowledge related to the unit's scientific and engineering concepts as a result of their participation in the design-based lesson. While statistically significant pre-test to post-test gains were observed across all four of the participating teachers' classrooms, there was variability in student performance. The posttest scores were highest in Harold's and Molly's classrooms. In addition, higher gains were recorded in the classrooms of Harold (5.13 or about 43%) and Molly (4.46 or about 37%) compared to those of Opal (2.52 or about 21%) and Pam (2.32 or about 19%).

Table 7 shows the knowledge test results for the Slow Boat task. The results are similar to those for Door Alarm though some less variable. Across all four teachers, on average, students scored 5.82 (about 49%) on the pre-test and 9.24 (about 77%) on the post-test, a gain of 3.42 (about 28%), which was statistically significant ($t = 11.63$, $p < .0001$). Again, this suggests that the grade 4 students developed their understanding of content knowledge related to the unit's scientific and engineering concepts. Statistically significant pre-test to post-test gains were observed across all four of the participating teachers' classrooms, but as with the other task there was variability in student performance. The posttest scores again were highest in Harold's and Molly's classrooms. In addition, higher gains were recorded in the classrooms of Harold (4.43 or about 37%) and Molly (4.17 or about 35%) compared to those of Pam (2.57 or about 21%) and Opal (2.26 or about 19%).

Overall, the results suggest that students developed their understanding of content knowledge related to scientific and engineering concepts as a result of their participation in the design-based lessons. Pre-test to post-test performance of students showed increases across both tasks. However, for both design tasks, there was variability in student performance by teacher. This observed variation in student performance may relate to the fidelity with which teachers implemented the lessons.

Table 6. Students' Pre- and Post-instruction Knowledge Test Scores by Teacher for the Door Alarm Task

Teacher	n	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD	Gain	t	Prob (t)
Harold	23	5.83	1.64	10.96	1.26	5.13	11.99	<.0001
Molly	26	6.50	1.58	10.96	1.15	4.46	13.01	<.0001
Opal	21	5.38	1.43	7.90	2.76	2.52	3.70	0.0014
Pam	22	6.05	1.43	8.36	2.32	2.32	4.46	0.0002
Overall	92	5.97	1.56	9.64	2.38	3.67	13.48	<.0001

Table 7. Students' Pre- and Post-instruction Knowledge Test Scores by Teacher for the Slow Boat Task

Teacher	n	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD	Gain	t	Prob (t)
Harold	23	5.91	2.09	10.35	1.40	4.43	10.78	<.0001
Molly	24	5.17	1.88	9.33	2.10	4.17	7.39	<.0001
Opal	19	6.21	2.27	8.47	2.65	2.26	3.09	0.0063
Pam	23	6.09	2.64	8.65	2.40	2.57	4.69	0.0001
Overall	89	5.82	2.23	9.24	2.25	3.42	11.63	< .0001

Relationship of Teacher Implementation to Student Performance

To assess whether there was a relationship between teachers' implementation of the design-based lessons and subsequent student performance, Pearson product moment correlations were calculated between the teachers' observational rubric scores, which measured the degree to which teachers' lesson implementations showed evidence of the engineering design practices encouraged by the project, and students' scores on the measures of achievement (the content knowledge post-test score and gain score) for each design task. The results are shown in Table 8.

As an initial check, we examined the correlations of teachers' average score across all rubric categories with measures of student achievement. The results indicated that there were small to moderate positive correlations between teachers' implementation rubric scores and students' achievement measures for each design task (r=0.39527 for Door Alarm Posttest, r=0.29525 for Door Alarm Gain, r=0.16141 for Slow Boat Posttest, r=0.25734 for Slow Boat Gain). Three of these four correlations were statistically significant. Of course, correlation does not imply causation, but these results suggest that how the teachers implemented the design-based lessons had an impact on their students' subsequent learning performance. These findings are consistent with a prior study of 5th and 6th grade teachers and their students which found a correlation between teachers' average rubric scores and student performance on corresponding content post-tests [4]. Given these findings, we wanted to examine if specific teacher practices correlated with student performance.

Table 8. Correlations of Teachers' Rubric Scores with Student Posttest and Gain Scores for Each Design Task [r, p(r), n]

	Achievement Measure			
Rubric Category	**Door Alarm Posttest**	**Door Alarm Gain**	**Slow Boat Posttest**	**Slow Boat Gain**
1. Ask questions	0.24332 0.0194 92	0.17156 0.1020 92	0.18136 0.0890 89	0.28980 0.0059 89
2. Express ideas	-0.01964 0.8526 92	-0.03072 0.7713 92	0.15394 0.1498 89	0.18223 0.0874 89
3. Share ideas	-0.01964 0.8526 92	-0.03072 0.7713 92	0.28060 0.0077 89	0.33869 0.0012 89
4. Collaborate	0.30211 0.0034 92	0.29225 0.0047 92	0.29319 0.0053 89	0.21834 0.0398 89
5. Use tools	0.51317 <.0001 92	0.42302 <.0001 92	0.07695 0.4736 89	0.00773 0.9427 89
6. Develop a model	0.59336 <.0001 92	0.45218 <.0001 92	0.28060 0.0077 89	0.33869 0.0012 89
7. Test solution	0.30211 0.0034 92	0.29225 0.0047 92	0.15394 0.1498 89	0.18223 0.0874 89
8. Communicate	0.51313 <.0001 92	0.38410 0.0002 92	-0.12199 0.2548 89	-0.03163 0.7685 89
9. Compare results and improve	0.34950 0.0006 92	0.19009 0.0695 92	-0.29319 0.0053 89	-0.21834 0.0398 89
10. Teacher as facilitator	0.39699 <.0001 92	0.29161 0.0048 92	-0.11150 0.2982 89	-0.01257 0.9069 89
Average of all categories	0.39527 <.0001 92	0.29525 0.0043 92	0.16141 0.1308 89	0.25734 0.0149 89

To assess the impact of specific teacher practices, we examined the correlations of particular rubric categories with the measures of student performance. A number of positive correlations between teacher rubric scores and student assessment scores were statistically significant. Across both design tasks, moderately strong positive correlations were observed between students' posttest and gain scores and two teacher rubric categories: *4. Collaborate* and *6. Develop a model*. These results indicate that for both engineering design tasks observed in this study, students performed better in classrooms where the teachers did a more effective job of fostering collaboration and the development of model to describe a design solution. Interview data further confirmed these results. Harold, Molly and Opal admitted that "students working in design teams," "collaborating together on their designs," and "creating models of their designs" were all "beneficial for students to experience and learn design first hand" (Interview #2). This suggests that fostering collaboration and model development may be important teacher moves for successful implementation of engineering design activities in the elementary classroom regardless of the specific design activity.

It is notable, however, that other teacher actions correlated with positive student outcomes on one design task versus the other. For example, in the case of the Door Alarm task, several moderately strong positive correlations between student performance measures and specific teacher rubric categories were noted. These rubric categories included: *5. Use and access to a range of tools*, *7. Test proposed solution of a design*, *8. Communicate*, and *10. Teacher as facilitator*. The corresponding correlations between these rubric categories and student performance on the Slow Boat task were not statistically significant. Similarly, in the case of the Slow Boat task, there were moderately strong positive correlations between student performance measures and the teacher rubric category *3. Share ideas*. The same relationship was not observed for the Door Alarm task. Curiously, in the case of the Slow Boat task, there were also significant negative correlations observed between rubric category *9. Compare results and improve* and the student performance measures. This anomalous finding suggests that teacher emphasis on examining results and improving on the design may actually have been detrimental to student performance on the Slow Boat task, which, as noted previously and supported by results from teacher interviews, is a task that is well suited to testing and redesign. The variations observed in correlations across tasks in these cases suggest that the nature of the specific design tasks required teachers to emphasize different aspects of the design process and/or design practices in order to help their students succeed.

Conclusion and implications

The purpose of this study was to examine grade 4 teachers' implementation of engineering design-based science instruction and the impact their instruction had on student learning. Results indicated that three of the four teachers in this study were effective at implementing engineering design-based science instruction. One teacher demonstrated progress from low to moderate fidelity of implementation. Results from teachers' implementations indicated that certain instructional strategies teachers employed correlated positively with students' performance on knowledge assessments. In short, teachers who demonstrated relatively high fidelity of implementation of design-based instructional strategies, in particular fostering collaboration and model development among student design teams, had students who performed well on the knowledge assessments. Additional interpretation of data suggests that the nature of design task may be a mitigating factor in how and what instructional moves teachers prioritize and how students perform. Hence, we contend that teachers and students within the partnership actualized a community of practice where learning and teaching of science through engineering design was enacted and achieved.

It is important to acknowledge the study's limitations. The number of the unit of analysis used in this study may be considered small. As statistical tests normally require a larger sample size, this study was limited to four teacher classrooms. By incorporating data from additional classroom settings in future studies, the data might be more generalizable. Another limitation is the composition of the study sample. The sample identified in this study was from a single suburban school district and had limited racial/ethnic diversity. Prior studies within the context of the partnership have included samples of participants more representative of the overall diversity of the partnership [4]. Lastly, the study did not incorporate a control group. The aim of the study was to examine what strategies teachers employ and if and how their implementation influenced student learning. Comparing these results with more traditional science classrooms would provide more generalizability of the results to a larger population where conclusions about causality could be more definitive.

Results from this study suggest that elementary school teachers' undertaking of sustained engineering design-based instruction may provide opportunities to further explore not only how teachers enact design-based pedagogies but also how students learn. In what ways could elementary school teachers' multiple enactments of engineering design-based instruction influence students' longitudinal development of science and engineering core disciplinary ideas? How do elementary school students purposefully use science when engaging in engineering design tasks? To what extent do students connect individual scientific concepts together in the context of an engineering design-based task and how enduring and accurate are these connections? By exploring further these questions we can gain a better understanding of how to identify the most effective pedagogical practices for improving design learning; useful approaches to science teacher professional development and curriculum design; and sustainable and scalable resources for both inservice and preservice teachers.

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References

[1] National Research Council, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington, DC: National Academies Press, 2012.
[2] Next Generation Lead States, *Next Generation Science Standards*. National Academies Press: Washington DC, 2013.
[3] J. Lave and E. Wenger, *Situated Learning: Legitimate Peripheral Participation.* Cambridge, England: Cambridge University Press, 1991.
[4] B. Capobianco, J. D. Lehman, Q. Huang, and C. Nyquist, "Impact of elementary school teachers' enacted engineering design-based science instruction on student learning," in *Proceedings of the 2016 American Society for Engineering Education Annual Conference*, paper ID#14947, 2016.
[5] J. Gee, *Social Linguistics and Literacies: Ideology in Discourses.* 3rd ed. New York: Routledge, 2008.
[6] M. Cochran-Smith and S. Lytle, "Relationships of knowledge and practice: Teacher learning in communities," *Review of Research in Education,* vol. 24, pp. 249-305, 1991.
[7] V. Vescio, D. Ross, and A. Adams, "A review of research on the impact of professional learning communities on teaching practice and student learning," *Teaching and Teacher Education,* vol. 24, pp. 80-91, 2008.
[8] J. D. Lehman, W. Kim, and C. Harris, "Collaborations in a community of practice working to integrate engineering design in elementary science education, " *Journal of STEM Education: Innovations and Research*, vol. 15, no. 3, pp. 21-28, 2014.

[9] M. Patton, *Qualitative Research and Evaluation Methods*, 3rd ed. San Francisco, CA: Sage Publications, 2001.
[10] B. M. Capobianco, C. Nyquist, and N. Tyrie, "Shedding light on engineering design," *Science and Children*, vol. 50, no. 5, pp. 58-64, 2013.
[11] D. C Eichinger, E. K. Doherty, J. D. Lehman, and V. Merwade, *Design of a Door Alarm*, 2013. [Online]. Available: https://stemedhub.org/resources/1772. [Accessed March 1, 2018].
[12] B. Hubbard, A. Panitch, T. Reid, K. Clase, N. I. Tyrie, and J. D. Lehman, *Slow Boat*, 2013. Available: https://stemedhub.org/resources/1780. [Accessed March 1, 2018].
[13] Creswell, J., & Creswell, D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 5th ed. San Francisco, CA: Sage Publications.
[14] B. M. Capobianco, J. DeLisi, and J. Radloff, "Characterizing elementary teachers' enactment of high-leverage practices through engineering design-based science instruction," *Science Education*, vol. 102, no. 2, pp. 342-376, 2018.
[15] B. M. Capobianco and M. Rupp, "STEM teachers' planned and enacted attempts at implementing engineering design-based instruction," *School Science and Mathematics*, vol. 114, no. 6, pp. 258-270, 2014.
[16] J. Strauss and A. Corbin, A., *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*, 4th ed. San Francisco, CA: Sage Publications, 2014.

APPENDIX A
Engineering Design-based Classroom Observational Rubric

Source: Capobianco and Rupp [15]

Key elements		*0*	*1*	*2*	*3*	*4*	*Not observed*	*Score*
		Never occurred	←--→			*Very descriptive*		
1	**Ask questions and define features of an engineering problem (i.e., criteria, constraints, goal, end user, client and client's needs).**	Teacher does not address nor discuss the essential features of the design brief.	Teacher verbalizes the essential features of the design brief to students. Entails a lot of teacher-directed instruction.	Teacher instructs students to identify or recall some of the essential features. Students are guided or coached through the protocol.	Teacher encourages students to identify or recall most of the essential features. Students need guidance and direction.	Teacher encourages students to identify or recall and record the problem statement, client, end user, criteria, constraints, and goal. Students appear self-directed and familiar with the protocol.		
2	**Express individual ideas in writing using models or drawings.**	Teacher does not allocate time for individual planning. Students do not express individual ideas.	Teacher provides a refined solution to individual students. Students are given possible solutions.	Teacher provides guidance or encouragement for students to develop individual solutions. Students are guided or coached through individual planning.	Teacher encourages students to generate and express practical, individual solutions that align with most of the essential features. Students require guidance and direction.	Teacher focuses students on developing individual feasible and detailed solutions that align with the goals, client's needs, criteria, and constraints. Students appear self-directed and cooperative.		
3	**Share individual ideas orally and express group ideas in writing.**	Teacher does not allocate time for team planning.	Teacher provides a refined solution to all student teams. Student teams are given refined solutions.	Teacher provides guidance or encouragement for students to negotiate and decide on one solution.	Teacher encourages student teams to develop one feasible solution that aligns with most of the essential features of the task. Student teams seek guidance from the teacher.	Teacher encourages teams to negotiate and decide on one feasible solution that aligns with the goals, client's needs, criteria, and constraints. Teacher and/or students encourage input from all team members. Group consensus is achieved by most teams.		
4	**Collaborate with one or more peers throughout the design process for the selection of the most promising solution.**	Students work individually or work independently in a team.	Teamwork is occasionally incorporated into the design lesson.	Teamwork is partially incorporated into the design lesson. Less than half of the student teams work as a unit; share ideas; or complete the task. There is little to no negotiation or compromise among team members.	Teamwork is frequently incorporated into the design lesson. The majority of student teams attempt to work as a unit; share some ideas; partially complete the task. There is some level of negotiation and compromise among team members.	Teamwork is incorporated throughout the design lesson. Student teams are high functioning; share and negotiate ideas equitably; share responsibilities; and complete the task.		
5	**Use of and access to a range of tools and manipulatives to construct and test a promising solution.**	Teacher does not allocate time for students to manipulate materials or tools.	Teacher limits the range of materials, tools, and the amount of time necessary to complete the task.	Teacher limits access to the materials and tools during individual or team planning. Teacher demonstrates the use of materials or tools with little to no student manipulation of materials or tools.	Teacher provides access to a range of materials and tools during individual/ team planning or construction. Students manipulate materials or tools.	Teacher provides multiple opportunities for students to observe, handle, or test out a range of materials and tools throughout planning and construction. Students use materials and tools to inform their design solutions.		

6	**Collaboratively develop a model using an analogy, example, or abstract representation to describe a design solution that aligns with essential features of the engineering problem.**	Creation of a design is incomplete.	Creation of a design is disorganized; unclear; and does not meet the client's needs or constraints.	Creation of a design is somewhat disorganized; aspects of the design do not align with the design plans, client's needs, or constraints. Teacher-student interactions are initiated and directed primarily by the teacher.	Creation of a design is somewhat organized; some aspects of the design align with the design plans; and meets some of the client's needs and constraints. Teacher-student interactions are infrequent.	Creation of a design is organized, aligns with design plans, and meets the client's needs and constraints. Teacher -student interactions are frequent and constructive.		
7	**Test proposed solution of a design. Use data and scientific concepts to evaluate and refine design solutions.**	Student teams do not conduct testing, evaluation or analysis of solutions.	Student teams conduct limited testing, evaluation, and analysis of solution performance.	Student teams conduct testing, evaluation, and analysis of solution performance.	Student teams test their solutions, collect and display data, and discuss overall results.	Teacher is focused on encouraging student teams to test their solutions, collect and analyze data, and explain the relationship between results and overall performance.		
8	**Communicate clearly and persuasively the ideas, final design solutions, and related performance results using relevant evidence about how it meets the criteria and constraints of the problem.**	Teacher does not facilitate opportunities for students to review, reflect or communicate performance results.	Teacher limits opportunities for students to review, reflect, and communicate performance results.	Teacher fosters communication of original ideas; final design; and performance results.	Teacher fosters communication of original ideas, final design, and performance results. Teacher encourages students to evaluate their designs based on what worked and what did not work with no reference to meeting the original goal, client's needs, and constraints.	Teacher fosters clear and persuasive communication of original ideas, final design, and performance results; and elaborates on how designs met the goal, client's needs, and constraints. Teacher explicitly encourages students to consider improvements to designs.		
9	**Compare performance results and revise and improve designs.**	Teacher does not encourage students to re-design.	Teacher limits opportunities for student to re-design, re-test or improve on the overall performance of the design.	Teacher encourages teams to improve and retest with minimal guidance. Teacher does emphasize a record of the revised solution, re-testing, or evaluation.	Teacher encourages teams to re-design one feature of the team's design and record a revised solution. Teacher limits opportunity to re-test and evaluate the performance. The re-design does not make the solution better; however, it represents a plausible attempt.	Teacher encourages teams to re-design one or more feature(s) of the team's design and record a revised solution. Students re-test and evaluate the performance. The re-design may make the solution better.		
10	**Teacher as facilitator**	Teacher-student interactions throughout the design lesson are absent.	Teacher is directive or prescriptive in teaching engineering design practices. Teacher-student interactions are minimal.	Teacher occasionally guides students by listening, observing, and questioning students. Responses are primarily teacher-directed or initiated.	Teacher guides students by listening, observing, and questioning students. Responses emerge from students' ideas or questions. Teacher attempts to refocus students to essential elements of the design task.	Teacher guides students by listening, observing, and questioning students. Teacher builds the lesson around students' ideas and questions while continually refocusing students to the essential elements of the design task.		