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Elementary Teachers' Two-Year Implementation of Engineering: A Case of Success

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I. Introduction

Recent years have brought about an educational movement to bring engineering into K-12 classroom. While historically, most public schools have not taught engineering to all students, the Next Generation Science Standards[1], currently under revision, include the integration of engineering. This marks a turning point and historic moment for K-12 education, and for engineering education. This is a great window of opportunity for educational reform, and yet, despite the haste to meet the challenge of bringing engineering into classrooms, there are still many unanswered questions about what will make this work best. One of those questions is about how to create effective and sustaining teacher professional development (TPD) for engineering. This is a significant challenge for the engineering education community, as high quality TPD is essential for any educational reform effort to result in truly positive, enduring change.[2]

In addition, requiring teachers to teach subject matter that they are not trained or educated in is detrimental to both teachers and students.[3] Considering engineering is a subject where a majority of teachers have not received formal pedagogical or content training during their teacher preparation program *and* have no prior experience being K-12 students of the subject, the barriers they face approaching engineering professional development are arguably beyond that of professional development in any other subject area. To shed light on what is needed to overcome these hurdles effectively, for truly sustaining change, it is important to closely examine the process and outcomes of successful cases of implementing engineering in elementary classes.

Purdue University's Institute for P-12 Engineering Research and Learning (INSPIRE) has been involved in TPD for engineering since 2006. In addition to trainings located on University campus, INSPIRE with support from the National Science Foundation, has provided five years of TPD for engineering in one school district located in the Southern United States. Throughout the course of working with multiple schools in that school district, some teachers communicated that they would no longer participate in engineering. The district adopted new testing standards the second year of our project and many teachers reported stress related to the new associated curriculum and amount of time spent testing. As is the case for all teachers, especially in grades with high-stakes testing, instructional time is quite valuable; doing anything above and beyond what directly maps to the standards could be viewed as an inefficient use of time. Engineering standards were not part of the new district standards, yet our experience was that some teachers, particularly cohorts from the same schools, continued to be enthusiastic about teaching engineering and considered it important. The purpose of this study is to explore one such elementary school's experience in implementing engineering and the resulting student outcomes.

A case study research method is used to illuminate a specific decision or set of decisions through answering *why* the decision(s) were taken, *how* they were implemented, and with *what* resulted.[4] While the final outcomes are still in process for a larger case study, the current study will focus research questions on the first two-years of implementation: (1) What were teachers' perceptions about the value of teaching engineering to elementary students? (2) What type of in-school support did teachers receive to teach engineering to elementary students? (3) How did teachers implement engineering into their elementary classes? (4) What were the changes in students' science, technology and engineering knowledge? (5) What were the changes in students' engineering identity development?

II. Teacher Professional Development Literature Review

The literature on TPD is somewhat nuanced in terms of when it is effective.[5] There are several models and approaches to training teachers, and it is clear that there is no one "best" model.[2] However, in a synthesis of the TPD literature, Guskey and Yoon[5] note that the characteristics most frequently cited as essential for effective TPD are increasing teachers' content knowledge and their pedagogical knowledge. In a survey of 1,027 nationally sampled teachers, researchers found that teachers viewed TPD as being most effective when (1) there is focus on content knowledge, (2) there are opportunities for active learning, and (3) there is a coherence with other educational objectives.[6] In a study of science TPD, teachers' understanding of content had a strong influence on their teaching practice, and the classroom culture.[7] Brophy and colleagues argue that teachers need to be comfortable and proficient with the engineering design process, as well as pedagogy in order to maximize student learning.[8] Brophy and colleagues also call for more research to determine the level of preparation teachers' need to be able to effectively adopt and adapt engineering curriculum.

The importance of content and pedagogy are not always carefully considered in TPD for engineering. In a multiple case study of TPD for engineering, all five programs examined focused heavily on modeling and applied learning, rather than on having a solid conceptual foundation for engineering[9]. In other words, teachers were only trained to teach the curriculum handed over to them, not anything beyond that. Going from zero knowledge in a subject to being able to teach it to a class full of students, through a workshop or other training, is a formidable task. It is understandable why programs may take a more pragmatic approach to focusing on "what teachers' need to present" rather than treating teachers as active learners who are vested in their own professional development. However, such an approach runs the risk of diminishing outcomes in terms of teacher knowledge, rather than building a foundation for a career in teaching engineering. Professional development is not something that simply happens to teachers; there must be a process whereby teachers learn and the outcome of that is their professional development. For TPD efforts to sustain, teachers must be treated as active participants in their own growth.[10] Teachers must be actively engaged and develop a sense of collaboration with each other and their university partners.[2]

What is reasonable to accomplish at a one-week academy, in terms of engineering knowledge, beliefs, and attitude change, needs to be explored, as well as what happens through the course of ongoing support and implementation. Lasting professional development does not end at the closing of a workshop, rather teachers go back and implement in the context of their school. This context is important; what is going on in the school and district socially, economically, and politically will have an influence on how well the educational initiative associated with the TPD is realized.[11]

For more than twenty years, networks of teachers have been found to aid sustaining educational change.[12] Groups of teachers can come together and foster a culture of common understanding for instructional goals, methods, and solutions.[6] In this way, the TPD is expanded from an individual learning experience to an organizational learning experience. The TPD can provide opportunities for discussion, reflection, and debate.[6] In the same way, groups of teachers could pose a negative influence on the effort if they do not see the value of the content being learned. Van Driel, Beijaard and Verloop[13] found that science teaching reform efforts were largely ineffective in a number of countries, largely due to a failure of the TPD program to account for teachers' attitudes, behavior, and knowledge.

Administrative support is also a key ingredient to lasting education change from TPD.[2] If teachers have bought-in to the reform effort, but administrative support is not present, any learning gains established through the TPD will not transfer to long-term improvements. Lasting educational reform is dependent upon administrative and teacher support.

III. Project Background

Over the last six years, our team has been providing TPD academies which focused on integrating engineering into elementary classrooms. For this current project, teachers from elementary schools in a large school district in South Central United States volunteered for the professional development. In order to be accepted, teachers were required to commit to two years of implementing engineering and working with our research team. A two-year commitment was required for teachers to build upon the conceptual foundation of technology to a deeper understanding of the engineering design process. Teachers were not required to have previous STEM certification or training beyond their teacher program. The commitment involved participating in a one-week long workshop the first summer and an additional three day follow-up the following summer, teaching engineering in their classrooms in the year following each TPD workshop, facilitating student assessments, and participating in teacher data collection including online lesson debriefs and end-of-year interviews. During the academic year, a liaison to the Institute provided occasional addition afterschool workshops and was available for in-class support.

One school, Orchard Groves (pseudonym), continued to have additional teachers volunteer for TPD in engineering, year after year. Some of these teachers adopted, adapted, and created engineering curriculum beyond that which was included in the TPD provided. In addition, some teachers have gone on to become engineering TPD providers for the district and beyond. Based on their level of enthusiasm, we chose to examine their process of implementation and what outcomes this produced. This case study is focused on the first cohort of teachers from Orchard Groves.

A. Summer Academy

Thirty-two teachers (cohort 1) attended the engineering summer academy in 2008. Teachers volunteered to participate in teams of 4 or more. During the 2008 academy, teachers learned about technology, engineering, the engineering design process, and mathematical modeling. They participated in scientific investigations, and engineering design challenges, and they developed solutions to model-eliciting activities (MEAs). MEAs are complex, open-ended, authentic mathematical problems, requiring teams of students to analyze data and work together to develop a procedure, or mathematical model. The MEAs that the teachers completed were developed at the Institute, and were piloted with classes of students beforehand. The design challenges that the teachers participated in came from the Engineering is Elementary (EiE) curriculum. EiE is housed at the Museum of Science in Boston, and has developed a set of twenty engineering units, each focusing on a different engineering discipline. Each unit is comprised of an engineering story which introduces the problem, a lesson on the specific engineering discipline, a scientific investigation, and a design challenge which is centered on solving the problem introduced in the story. Teachers had an opportunity to develop and implement short lessons with groups of 3-5 students. The following summer, 2009, twenty-one teachers returned for a 3-day follow-up engineering workshop. At this workshop, teachers participated in additional engineering design challenges and MEAs, but they also had the opportunity to reflect on their experience with integrating engineering and share ideas for future implementation.

Due the distance between the school district and the Institute, academic year TPD was limited. The Institute's on-site liaison provided some additional after school support, typically review, and was available to assist in classrooms on an on-call basis.

B. School

Orchard Groves elementary school is located in a large suburban area of south-central United States. This school was one of eight represented in cohort 1. In the first year, the school was not a Title I school, but in the following year it was entitled as a Title I school due to a slight increase in the percentage of students qualifying for free or reduced lunch. School size in 2008-09 was 932 students with 81% being minority students. Student to teacher ratio in this school was 18.1. In 2009-2010, there were 950 students with 82.3% being minority students. Please see Table 1 for detailed demographic information.

Table 1. School Characteristics in 2008 and 2009[14]

Characteristics	2008	2009
School Size	932	950
Title I status	No	Yes
Free/Reduced Lunch Status	40.0%	43.0%
Students' Gender		
Boy	51.2%	50.8%
Girl	48.8%	49.2%
Students' Ethnicity		
American Indian/Alaska Native	0.2%	0.5%
Asian and Pacific Islander	21.9%	22.3%
Hispanic	20.4%	20.7%
Black	38.8%	38.7%
White	18.7%	17.7%

C. Teachers and Their Classes

The demographic information for all cohort 1 Orchard Grove teachers is shown in Table 2. None of the teachers had formal training or certification in science, math, or engineering fields prior to the academies. One teacher previously worked with technology as a production manager. Table 3 shows the total number of students and the number of males and females for each teacher.

Table 2. Demographic Information of the teachers as of 2008

Name	Camille	Joe	Brandy	Heather
Gender	F	M	F	F
Race	White	White	White	White
Age in S08	49	56	48	39
Teaching grade	2	2	3	4
N. of students with survey records	10	13	17	20
Education	Bachelors (Sociology)	BA and M.ED.	Bachelors	Bachelors (Political science)
Certificate	ESL	—	—	ESL
Other career		Production Manager in Performing Arts dealing with light and sound design		
# of years as a full-time teacher as of 2008	7 years	7 years	4 years	7 years

Note. Teachers have been given pseudonyms.

Table 3. Number of Students in each Classroom

Name	Grade	2008			2009		
		N_T	N_F	N_M	N_T	N_F	N_M
Camille	2	10	5	5	14	6	8
Joe	2	13	5	8	16	9	7
Brandy	3	17	7	10	14	8	6
Heather	4	20	9	11	19	8	11
Total		60	26	34	63	31	32

Note. N_T = Total number of students; N_F = Number of female students; N_M = Number of male students.

IV. Methods

To answer our five research questions in a comprehensive way that would result in a case study, we utilized four sources of data, both qualitative and quantitative. The research questions and procedures used are described below.

A. Qualitative Methods and Procedures

Considering the restraints placed on teachers and that teaching engineering was not required in their district, we sought to find out *why* teachers would want to continue teaching engineering. Specifically, we asked (1) What were teachers' perceptions about the value of engineering in elementary school? (2) What type of in-school support did teachers receive to teach engineering? Next, we wanted to find out *how* teachers were teaching engineering. We asked, (3) How did teachers implement engineering into their elementary classes?

Interview protocols were designed to draw out teachers' perspectives and experiences with implementing engineering. Specifically, questions were developed to explore teachers' knowledge and attitudes about engineering, pedagogy, administrative support, teacher perceptions of students' learning, and teachers' choices about professional development. A different protocol was used each year. The protocol was changed in the second year to better capture the teachers' experience. The protocols can be found in the Appendix.

Researchers interviewed all four teachers from Orchard Groves. Interviews took place twice; once at the end of each school year that engineering was implemented. Each interview lasted 30-45 minutes. Through a collaborative and participatory process, interviews verbatim transcripts were analyzed inductively, following guidelines for inductive analysis as described by Patton (2002). The two years of interviews were analyzed separately and treated as two sources of data. This involved several steps. First, two researchers read the first-year interviews and made notes in the margins, taking notice of patterns and open-coding, to allow codes to be generated. Then, the researchers independently created a list of potential codes and came to consensus on a coding scheme. Next, two researchers went through all first-year interviews and coded the data with the coding scheme. Researchers met and went through each interview, coming to a consensus on how the data were coded. Through collaboration and discussion, full consensus was met with each interview. A matrix was designed to log the frequency of the codes occurring per interview. The second year of interviews went through the same process, using the codes established with the first year data. From the codes, broader categories emerged. Codes that were consistent between years are reported.

B. Quantitative Methods

To study students' outcomes in engineering knowledge and their engineering identity development, survey pre/posttests of the Student Knowledge Test (SKT)[15] and the Engineering Identity Scale (EIDS)[16]. The pretests were administered to students at the start of each school year, and survey posttests administered at the end of each school year. The SKT was used to assess students' knowledge about science and engineering. The SKT has a different version for each grade and is mapped to the EiE units that are taught for that grade. The results for each grade level are reported through descriptive statistics. The EIDS was used to assess students' engineering identity development. The EIDS consists of 16 items rated on a three-point Likert-style scale to measure students' development in two areas: academic and engineering career. The academic factor is designed to measure how students' views themselves in relation to being a student. It was not expected that this would change, as there was no intervention related to student identity in the general sense. The engineering career factor is designed to assess students' aspirations in pursuing an engineering career. The results are reported in descriptive statistics for each year and both years are combined in a paired samples t-test.

V. Results

A. Teachers' Perceptions about the Value of Engineering in Elementary School

The following categories related to teachers' perceived value of teaching engineering emerged from the semi-structured interview data: student learning, teamwork, and student engagement. Each category is discussed and quotes from both years are given to support the discussion of the category.

Student Learning. Teachers perceived that students were pushed to learn skills not otherwise taught. Teachers reported that students were being challenged through the activities, both by the actual engineering design process, as well as by working in groups. Teachers communicated that they believed the engineering activities promoted deeper thinking and being more thoughtful before action. Teachers also reported that the learning in engineering activities supported skills needed for the standardized tests.

Quotes from Year 1

Heather: *The biggest part of this is that kids really do teach each other things when they are put in that situation. They really are good at relating what they are thinking to each other, as opposed to a teacher standing up there and saying the exact same thing and it not making sense to the kids, so kids do a very good job of teaching each other and pulling the best out of each other. You know, I was very surprised that some of my lowest kids were my kids that actually problem solved better and in the engineering setting than what they do in a regular classroom setting… For them it was hands on and it was more real world to them maybe than as the math problems that they give…they just just did a really good job of looking at the problem in front of them; looking at the challenge in front of them and coming up with viable input and ideas. I think that built a lot of their self-confidence because the other kids were listening to them- because that doesn't happen very often in the classroom.*

Joe: *They went from thinking an engineer was somebody that drove a train to that actually was a person that usually has a higher level education and is involved in so many different things, I mean, by the end of the year, they realized that….Some of them even started talking about video games, that an engineer would be involved in that process, so yea, I think that they made some pretty good connections and leaps as far as what they thought in the beginning to the end of the year.*

Quotes from Year 2

Brandy: *Well, I always want them to put thought into it. I'm a big proponent of you know, "let's plan it first and look at it and then go on." But actually putting it into those stages of the process, I saw them developing skills that I probably haven't developed before….Really deeper thinking. I always wanted that, that's my objective, but this- to break it into the parts and to see the sequence and have go into deeper thought after they planned it, and to actually take their plan and look at it better or a little deeper than they normally would, and I was doing that, too. You know, it cause me to do that, too, and me to question in a different way- Okay, why are you doing that? Is this going to get you where you want to go? Different kinds of questions that I came up with to guide them more to get the process.*

Joe: *So, I'm not concerned about the fact they haven't ever done it. But, if I can relate it to something they have done, to me, that's what really scaffolding is. It's not necessarily saying, "Okay this kid doesn't know anything about it," but finding out what they do know and say, "Well, you know, you've done this, and it's kinda like that."*

Heather: *And for fourth grade, the [standardized] test that we take, that's all it is; there's no straight out-multiplication, no straight-out division; it's all tied into a word problem. And to me, that's what the kids get from this, is "Here's your problem. What are they asking you to do? What are they asking you to solve?" And the kids get stronger with that when they figure out the problem-solving. Also, they get it a little bit into the reading when you have a problem, and that helps them figure out what the solution is later, by knowing "Okay, I can identify here's my problem, and then I can identify how the person fixed it later." And they do better with that with the engineering, I think.*

Camille: *I think they began to think more strategically and think more about problem-solving: "How can we fix this?" I think we see that [type of thinking] in all the other areas, just the thinking part.*

Student Team Work. Three of the four teachers discussed the value of students working in groups in terms of learning content, as well as social skills. They saw students learning from each other and working together to achieve the projects.

Quotes from Year 1

Brandy: *I'll do it even you don't come back next year….Because I think it helped with the team work. It helps, I think, their thinking a little bit above and beyond, you know, multiple choice or you know, so many of the things we're testing on, you know, paper and questions and answers, you know.*

Heather: *We- we were really teaching them how to work in teams first, how to get along, what was appropriate, you know how we ask for things and how we discuss things. That's very important after six weeks with our kids, what's acceptable in the classroom as far as working in* *groups. So, after we did that…then, we went back and we talked about why or why not their tables were successful.*

Quotes from Year 2

Brandy: *I think they grew, too, and they learned to appreciate teamwork more because the end process they liked. They didn't think they were going to enjoy it because they wanted to do it their way. Not all of them, but a few. You know, there's always a few. But the end product they were very proud of, and it was a team effort. So I really liked how that came together and the end result, because they were very, very, proud and wanted to them off. So, I really enjoyed that a lot.*

Camille: *First of all, teamwork. The fact that they're enjoying what they're doing, they want to do it; the conversations they have, you, watching 'em go through the process and then somebody will say, "Well, we need to rethink that." And that's when your jump-in moment is, and you ask, "Well, where are you on the wheel?" and they go, "Where are you?" "Oh, well, I guess we're….we've gone back to brainstorming."*

Heather: *…because it seems like they always have the same ideas of how want to be spoken to and how they want to be treated, and so it comes out really easily for them, you know, you know, and we just set up our little rules, and they know when they don't follow those rules, there's points taken off and then they're taken out of the group for a few minutes. And that five minutes out of the group makes a huge impact for them because they don't want to not get to work in the group, and they learn very quickly how to talk to their friends and how to treat their friends in the group and it's just helping those social skills of when they get bigger and have to work in a group.*

Student Engagement. The teachers discussed that for the most part, students wanted engineering lessons and were engaged in the activities. Teachers reported that students who were not the usual leaders in class also appeared to be engaged in the activities. Teachers perceived that students were able to learn from working with each other.

Quotes from Year 1

Camille: *I think they basically liked everything we did because it was hands on and fun.*

Brandy: *And just having a motivation, excitement. They were excited about, you know, when we culminated and talked about engineering and what all around us was involved.*

Brandy: *I loved it, because it was…it was exciting for them and challenging, you know, it was…it was difficult, so they did to make lots of improvement- they did fail, but it wasn't such a failure that they didn't want to try again. So, I really liked that.*

Quotes from Year 2

Brandy: *And it seemed like they were really enjoying it then and they understood a lot, so they could contribute more. They were more involved in it. It wasn't just showing it and talking about it at that time. And then it seemed to really stick. They understood- most of 'em.*

Heather: *Very well. They [students] love it. They can't wait to do it, and they get mad when we don't get to do it.*

Camille: *I can't say that there's anybody in here that we've had since the beginning of the year that does not get excited about the idea of doing something with engineering.*

Joe: *The nucleus, I'd say, it goes extremely well. They were excited about doing it every time we've done one, even one that I thought was boring that we did to try to build them up to it. That's what we tried to do: we tried to start small and build up. Anytime I said were going to do it, they were excited.*

B. Types of In-School Support for Teachers

Two categories emerged as types of support teachers discussed in their implementation of engineering in classrooms: teacher collaboration and school administration. Teachers consistently reported collaboration with each other, or responded to questions using "We …", rather than referring only to self. In addition, they also discussed that their school administration was very supportive of teaching engineering.

Teacher Collaboration. Teachers collaborated in meetings about lessons and shared resources. They also pulled classrooms together and co-taught, relying on each others' strengths, where there was uncertainty.

Quotes from Year 1

Brandy: *I really liked being able to work with another coworker. That worked really well because we could bounce ideas off each other and then as- as we were teaching, we could coordinate with each other like- it just happened so naturally. It was like, I tended to be the one that introduced more and then my coworker would bring in more background knowledge…rather to…because I teach third grade, she taught fourth grade…and how that all went together. So, I thought that worked really well. We enjoyed teaming up with that and towards- in the beginning, I was helping in her class and then she would come help in my class and then it got to be to the point where we were able to do both classes at the same time. At- once the kids understood what was we wanted them to do as far as understanding the design process and working in teams, then we could dive actually divide them up and have co-mingle fourth and third grade together….By that time, I think she and I both had enough confidence, our children understood what to do and then we worked on our own.*

Heather: *I had a partner here that was in third grade- and [teacher's name] and I matched up a lot, so that worked very well for us. You know, we pared up and what one us couldn't remember how to do or what one of us had an idea about, the other one you, would build off of that and it really made it a lot easier.*

Quotes from Year 2

Brandy: *And when I say "we" that means [teacher], that's because another co-worker and I partnered up and kinda worked through lessons together. I would go on my conference time and help in her room and she come on her conference time and help in my room, so those beginning lessons we really coordinated together.*

Camille: *We kinda worked together so that we had more than one adult in there when we were doing it with each other's class. So, when, you know, a student teacher was down here my class, then I was down there with him when he working with his class.*

Joe: *We try to collaborate. I'm lucky- and think what's kept me on this grade level- because I have teachers that really want to truly collaborate.*

Administrative Support. Teachers felt their principal was enthusiastic about engineering and truly supportive. They reported the principal would make announcements over the school intercom about the engineering lessons and invited teachers to come in to see activities. The teachers discussed this more in-depth in the first year.

Quotes from Year 1

Brandy: *They announce it on the intercom. They write it in the school newsletter. They announce it at staff development…they promote it….Ok, so I believe that they were very much, "Yes, let's try to get more people involved in it." Oh, and helping me clean up the science room. I actually had an administrator come down and do that because their science rooms sometimes get used for clutter.*

Heather: *Well, our principal, she'd come down and watch when we were doing projects. She'd told me to let her know when we'd be doing that in the classroom. She announced over the announcements when the kids were doing special, you know, something with the engineering project and I thought that was neat. The kids liked that….They were just very flexible. Any time we had the training on a Tuesday, that happens to be our faculty meeting day, you know, they would excuse us, you know go ahead and go to your engineering stuff. Just really, that's it. You know when someone is happy and when they are not. They were very happy we were doing it.*

C. Implementation of Engineering into Classes

In both years, teachers discussed that they went beyond the lessons given in the academies. They not only implemented the engineering lessons they were given, but also found more resources. The categories of implementation that emerged were: find more resources, integration with other subjects, and teacher reflection and modification.

Find More Resources. Teachers showed a learning attitude in that they went beyond just teaching with the materials given at the academies, to finding additional resources online or through personal connections.

Quotes from Year 1

Camille: *So we went and did some research online, looking at different inventors.*

Heather: *You know, every time before we would start one, she and I would sit and for an hour or two hours before we'd introduce it and we would go in and look for stuff on United Streaming [website] or we'd look for books that we could find. When we were designing our boats, we actually read a book on a new car, designing a new car and it was a little story; an engineering story. It went through, you know, about this dog that wanted to design a car and cool it was…it had engineering words in it. So, we did a lot of stuff trying to tie in extra things in before taught.*

Quotes from Year 2

Camille: *Because I found one online where you have to build a person out of gumdrops and toothpicks, and they have to be set on the edge of your desk…*

Heather: *That's why these two weeks I've got three different engineers coming in to talk to the kids, because I want the kids to understand the different types of engineering.*

Integration with Other Subjects. The Engineering is Elementary curriculum is designed to be integrated with science curriculum. The teachers discussed finding other ways of integrating engineering into other subjects and the potential of integrating engineering.

Quotes from Year 1

Brandy: *But even with technology, it's a social studies [standard in district test] so I counted that as my social studies for the day, so I was able, being a self-contained teacher, it makes it a lot easier to incorporate these activities in what I already know from our curriculum.*

Heather: *I think that definitely the design process to me was my most important focus. We even talked about it during reading and writing how we move the design process over into reading and writing with my kids and talked about how each phase of the design process is associated in other areas of their life and I think that was important because it gives them a lot of skills in that area to focus, you know, on each step and kinda give them a clearer picture of what they're looking for.*

Quotes from Year 2

Heather: *The writing, you know, my writing lesson came from "What is this problem? What are you seeing? What did you see about the culture?" I was able to tie in a lot more pieces, so I can take my writing grades and my reading grades from it…definitely give me more math things to do with my kids, you know, the MEAs, the projects to do with to see that. And I think it's wonderful.*

Bonnie: *Well, I think we're going to tie it in with A Chair for My Mother. Because I found one online where you have to build a person out of gumdrops and toothpicks, and they have to be set on the edge of your desk; and then the next step is the kids have to build some kind of chair for the person to sit on because- I mean, it's a story about a house that burns down and then mom wants a new chair. So, we're going to do that. We can tie it through math, language arts, maybe even social studies because they have a have a different cultural background.*

Brandy: *Every time we introduced engineering, technology, the whole process that they go through, and every time I did a science activity or a math activity that would coincide, I'd say, "Well, now, you know engineers are doing this." So, I tried to support it, wherever I could, throughout my curriculum.*

Reflection and Modification of Lessons. In the first year, the four teachers discussed ways they thought they could improve in their teaching practice. They also discussed meeting with other teachers and talking about implementation and how to improve. Teachers discussed making modifications to the lessons in order to improve how it was carried out in their classrooms and to make the engineering concepts more accessible to their students.

Quotes from Year 1

Camille: *There, you know, there are lots I probably would change just because I feel like I know a little bit more about it now….You know, be flexible….We did some changing, yeah…But, it was on the fly, rather than really planned, so I would like to you know, we're gonna sit down before we do [it]…*

Heather: *Next time I will summarize the first three chapters probably and then read four through six to them. Give them you know, definite specifics, but I think I'll just give them a back ground on first you know one through three and then get more specific by reading the story after that. I think I'll keep their attention better that way.*

Joe: *Definitely we have more English as a second language learners, so we had to worry about the vocabulary. Also, we had to build their foundation up of what they know, you know. You have to start with what they and Segway that with what they need to know, so you have to build that bridge.*

Quotes from Year 2

Heather: *It went better for me this year because I already had- I mean, I made a few tweaks and a few adjustment, but only to make it better, so I think that it went extremely well this year for me with already having the experience one year.*

Camille: *We had more emphasis on teamwork at the beginning of the year this year because, you know, we learned from last year that they have to be able to work as a team, and if they don't have that in place, then the rest of it won't come together….It worked a lot better this year.*

C. Students' Science, Technology and Engineering Knowledge

As mentioned previously, the SKT is grade specific, so pre/posttests were not combined for all students. In addition, in 2009, the 2nd grade version of SKT had a revision in the number of items. As shown in Table 4, students from all classrooms in both years experienced increased mean scores. Most notably, students in grades 3 and 4 experienced higher increases in mean scores.

Table 4. Students' Change in Science, Technology, and Engineering Knowledge Test Scores

Teacher	Grade	2008					2009				
		N	M_{pre}	SD_{pre}	M_{post}	SD_{post}	N	M_{pre}	SD_{pre}	M_{post}	SD_{post}
Camille	2	8	13.38	1.85	15.38	0.92	11	5.27	1.79	11.00	3.13
Joe	2	6	14.17	0.98	14.83	0.41	13	6.08	2.46	10.08	2.78
Brandy	3	14	3.65	1.78	7.57	2.38	13	4.85	2.12	12.00	1.73
Heather	4	16	7.75	2.87	10.06	2.74	18	8.67	3.14	11.28	1.87

Note. N = Number of students who took both Pre- and Post-tests

Students' Engineering Identity Development.

Table 5 shows the mean pre and posttest scores and standard deviations for 2008 and 2009. As expected, students did not experience significant change in pre/posttests on the factor of academic identity. Students in both years did experience mean changes in the engineering career factor. In order to determine the statistical significance, both years of data were combined for a paired sample t-test. Data from 2009 for students who participated in the project both years (with different teachers) were not included. The results indicate that on average, students' experienced significantly greater engineering aspirations after receiving engineering instruction (M=25.55, SE= 0.312), than prior (M=17.86, SE=0.398), with a large effect size, $t(94)=-16.01$, $p<0.01$, $r=0.855$.

Table 5. Students' Change in Engineering Identity Scale

Construct	2008					2009				
	N	M_{pre}	SD_{pre}	M_{post}	SD_{post}	N	M_{pre}	SD_{pre}	M_{post}	SD_{post}
Academic	45	15.76	1.79	15.78	1.91	61	15.66	1.73	15.10	2.42
Engineering Career	45	21.90	3.38	25.49	2.63	61	23.57	3.23	25.49	3.27

Note. N = Number of students who took both Pre- and Post-tests

VI. Discussion

This was a two-year study of one elementary school's teachers' process and their students' outcomes in knowledge and engineering identity. While the number of teachers in the first cohort is quite small, and a limitation to the study, the results can be used to inform TPD for engineering.

The teacher collaboration and administrator support at Orchard Groves is consistent with literature on the context needed for a lasting effect from TPD.[2,6,11] The administration not only gave the verbal "ok" for integrating engineering, but actually showed enthusiasm for the activities by drawing the whole school's attention to engineering. Administrators made announcements on the intercom, came to observe engineering activities, and assisted teachers in carrying out activities.

According to Guskey[11], teachers need to be actively engaged in their own learning and collaborate with others. Teachers at Orchard Grove worked together in learning engineering and teaching. They report planning lessons together, sharing resources, and co-teaching. Teachers discussed having a student teacher cover their own class, while they went to assist another teacher in carrying out an engineering activity. Other times, teachers actually combined their classrooms to do activities. The interviews indicated that this was a very collegial group of teachers.

In addition, Guskey[11] states that the most important characteristics of TPD are increasing teachers' content and pedagogical knowledge. As the teachers were implementing engineering into their classrooms, they continued to seek out engineering knowledge and collaborate on pedagogy. Teachers from Orchard Groves built on the knowledge learned from the academies by finding more resources. They showed ownership of the curriculum and created lessons beyond what was given to them at the academies. They were engaged in their own learning, as shown through their discussion of finding resources online and through outside connections. They reflected on their teaching and made adjustments to try to improve lessons. They found ways to integrate engineering into subjects beyond what was discussed at the academies. They saw application of the engineering design process to subjects outside of STEM, for example, social studies and writing.

Teachers from Orchard Groves saw value in teaching engineering to elementary students in the areas of student learning, student engagement, and team work. They perceived that students were learning not only engineering content, but also deeper knowledge of content in other subjects. They were able to find ways to use the engineering lessons to support district standards and actually considered the engineering activities to push students to deeper thinking. The teachers in grades with standardized testing discussed the learning as being supportive of district standards. Teachers also discussed the value of social skills that students were developing through group work and how students learned from each other. Teachers discussed high levels of student engagement and that students expressed interest in doing engineering activities. They also discussed students, who typically do not participate in class, becoming more involved in the engineering lessons than in other classroom lessons. These results serve as a starting point for future research on potential student outcomes when high quality TPD for engineering is implemented.

Teachers perceptions of learning gains and interest were supported by the results of the SKT and EIDS, which indicating that students improved in their knowledge of science, technology, and engineering through the course of one year, as well in their personal attitudes about being an engineer. According to Gottfredsons's Theory of Circumscription and Compromise, children ages 9-13 rule out careers they do not identify with, and may never again consider those occupations.[17] The finding that these children had a significant increase in their engineering aspirations is important in creating an open door for consideration of engineering as a career. According to career theorists, children need to learn relevant attributes of different occupations while their interests, skills, abilities, and values are still evolving.[17]

While many engineering TPD programs have a STEM certification prerequisite[8], none of the teachers from Orchard Groves had STEM certification or prior TPD in a STEM area. At the elementary level, teachers must be able to teach all core subjects; a prerequisite for STEM certification prior to TPD for engineering may rule out teachers who have potential to do well. The depth of STEM knowledge needed to teach engineering in elementary classes is not the same as what would be needed to teach engineering at high school levels. These teachers demonstrate that it is possible for "non-STEM" teachers to not only buy-in to engineering, but for their students to experience learning and interest gains.

VII. Implications

There is still much research to be done to inform how engineering can be integrated into elementary classes in an effective manner. The teachers from Orchard Groves shed light on what their experiences were with engineering in the classroom and also what areas to emphasize in future TPD for engineering. Based on these findings, we offer the following suggestions for others interested in TPD for engineering in elementary classrooms:

- Prior to trainings, attempt to make contact with district administration in order to work together tofind coherence between district goals and the engineering curriculum
- Build teacher collaboration and co-teaching explicitly into training models, by partnering teachers during training to continue collaboration through first year of classroom implementation
- Encourage teachers to build content knowledge throughout the school year and give additional resources for use both at the training and at points during the school year
- Allow time for teachers to brainstorm subject integration possibilities and discuss how to align integration with their district's areas of emphasis

Future research comparing schools where engineering was enthusiastically implemented with schools where teachers no longer wanted to implement engineering would provide a better understanding of the critical factors for engineering to be successfully integrated into K-12 education. In addition, future research is needed to better understand student knowledge gains in engineering and the long-term impact on engineering aspirations.

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Appendix A

TEACHER ENGINEERING LESSONS IMPLEMENTATION INTERVIEW PROTOCOL 2009

The purpose of this interview is to reflect on your experience with implementing engineering lessons in your classroom. Your feedback is very important for helping improve our understanding of how teachers integrate engineering into their formal classroom curriculums and how this integration changes their teaching practice and their views on student learning. This interview will take approximately 60 minutes. All your responses to my questions will be recorded and later transcribed. At no time will I identity your actual name in the recording of your responses during this or any other interview. I will assign a pseudonym to your responses, and I will store and label all the recordings with the pseudonym.

Section A: Knowledge of/attitudes toward/behaviors about the subject matter

1. How did you introduce engineering to your students?
   What was one important idea that you wanted your students to take away from this introduction?
   Were there other important ideas that you wanted them to take away?
2. Can you briefly list the engineering activities that you did with your students after this introduction?
   (Interviewer: you might already have an EiE list from the debriefs and just be after anything else the teacher did related to engineering or the engineering design process)
3. To what extent did you teach the entire *Engineering is Elementary* (EiE) unit?
   (Interviewer: you might already have an EiE list from the debriefs)
   - *If teacher did not teach the entire EiE unit,*
     - Why did you not teach the entire unit?
     - What things prevented you from teaching the entire unit?
   - *All teachers*
     - What worked? What did not work?
     - In what ways did you feel prepared to teach the unit? In what ways did you not feel prepared?
     - What needs to be put in place to better prepare you to teach this unit again?
4. Did you purposefully modify lessons within the *EiE* unit? (Interviewer: meaning prior to implementation)
   - *If yes,* How and why did you modify the implementation of the EiE units?
5. Did you teach any part of the *EiE* lessons differently from what you planned – based on your students interests or misconceptions? Why?
   (Interviewer: this is getting at changes the teacher made along the way that were not intended during planning)
6. Did you explore engineering and the engineering design process on your own prior to teaching any engineering activities? What did you do? What did you learn?
7. How did you connect the engineering lessons to other subjects? Which ones?
   - Can you give me an example of how you integrated [math/science/technology/literacy/other] into your engineering lessons?
   - Did you connect engineering to standards for math, science and others? How?

Section B: Knowledge of/attitudes toward/behaviors about students as learners

1. What do you believe your students should learn about engineering?
2. What do you think students learned? How do you know?
3. Do you think your lessons changed your students' perceptions of engineering? If so, how?
4. What was your general observation of how the girls engaged in comparison to boys?
   - Did the boys and girls interact with each other? How?
5. Our goal is to make engineering education accessible to all. Were any accommodations made for different learners (non-native speakers? gifted?). If yes, for who and what?

Section C: Knowledge of/attitudes toward/behaviors about pedagogy

1. Did your students engage in group work during the activities?
   - Can you describe how you formed groups? (ability, gender, other criteria)
   - What worked?
   - What did not work?
2. What kind of strategies did you use to determine what students were learning? (<u>Interviewer: you could set a scenario in which the teacher is doing the Paper Table activity and wants to check on students understanding of the engineering design process</u>.) [e.g., posing open-ended questions, reading and commenting on the reflection students have written, asking students to explain concepts to one another, etc.]
3. What strategies have been effective for you in assessing what students have learned about engineering and the engineering design process? Why do you think so?
4. Has your teaching practice or beliefs about teaching or student learning changed as a result of bringing engineering into your classroom? How?
5. Do you think it is important to incorporate engineering learning activities into your classroom practice? Why or why not?

Section D: Pedagogical content knowledge/expertise

1. What resources did you use to plan instruction?
   - If you had questions or problems in implementing instruction of the EiE unit, where and who did you go for help?
2. Looking back on this past year, do you see these engineering lessons as isolated, stand-alone activities or as an extension of your curriculum?
   - What is needed to move them towards seamless integration?

Section E: Choices about professional development, conferences, networks

1. If you could showcase something you created to other school teachers, what would it be?
2. Think back on your experiences in last year's Summer Academy as well as your experiences in your classroom this academic year. Based on your experiences and what you did in your classroom.
   - Is there anything you think we should do differently in the coming Summer Academy to prepare the next cohort?
   - Which parts of the Summer Academy should we keep?

3. We would like to seek your input on the content and delivery of Summer Academy II.
   - What topics would you like to be addressed?
   - How would you like this Summer Academy to be different?
4. Have you participated in any online professional development courses?
   - *If so*, how many courses have you taken?
   - What did you like about the course(s)? What did you not like about the course(s)?
   - How interested are you in online professional development program?
   - If we set up online professional development program, would you take it? Why or why not?
   - What specifically would you like to gain from online professional development program?

   (<u>Interviewer: If the teacher has no experience with online TPD, you could ask about other online learning resources or communities that they engage in and about the features they like and do not like.</u>)
5. Do you feel that your district administration is supportive of engineering education in any way?

Appendix B

Teacher Interview Protocol 2010

Interview Date: __________________
Time: Start: ______________ End: ______________
School: ____
Teacher: ____

Basic Descriptive Information of the Lesson
1. Teacher Gender: _____ Male _____ Female
Teaching Experience: _____ 0-3years
_____ 3-7years
_____ Longer than 7 years
2. Grade Level(s): _________

Section A: Knowledge of/attitudes toward/beliefs about the subject matter

1. Can you briefly describe your general approach/principle to teaching engineering in your class? [e.g., basic concepts, matching with TEKS, connection to daily life, etc.]*
2. To what extent did you follow the sequence of the EiE units when you teach engineering design process? (lesson 3 & 4)**
   - *If you have not completely followed,*
     - What barriers of teachers' preparation/participation were considered during engineering design process units?
   - *If you have followed overall,*
     - What facilitators of teachers' preparation/participation were considered during engineering design process?
     - Was there anything taught differently from what you planned?
   - *If you have modified the units to teach your class*
     - How and why did you modify the implementation of the EiE unites?
3. To what extent did you become knowledgeable about engineering and engineering design process in order to teach your students, and how best to teach those to students? ***
   - What factors did affect you to become knowledgeable about teaching engineering and engineering design process?
   - What factors did influence your best teaching?
4. How did you describe the goal of teaching your students engineering? Why do you think so? ****
5. What unit is the best/worst unit you have taught? Why do you think so?
   - What success/failure factors were considered in engineering design process units? Why?

Question	**Teacher Debrief Related to the question**
1	1, 3, 4
2	1, 2, 4
3	1, 4
4	4
5	1,2, 3,4

Notes
* 1 overlaps Section D: Pedagogical content knowledge/expertise.
****** 2 overlaps Section D: Pedagogical content knowledge/expertise.
***3 overlaps D: Pedagogical content knowledge/expertise.
**** 4 overlaps Section B: Knowledge of/attitudes toward/beliefs about students as learners and Section C: Knowledge of/attitudes toward/beliefs about pedagogy.

Priorities
2 > 1, 3 > 5> 4

Section B: Knowledge of/attitudes toward/beliefs about students as learners

1. How did you decide generally whether your students are developing concepts of engineering and engineering design process or not?*
2. How was your teaching constructed or changed your students' conceptions of engineering?
    - How did students connect concepts of engineering to their daily life?
    - How did students imagine the work of an engineer?
    - In what ways did the engineering activities inform students of what engineers do?
    - What kind of changes in students learning and achievement have you seen during engaging engineering design process (lesson 3 & 4)?
3. How did your students interact with one another to construct concepts of engineering and engineering design process?
4. Did you accommodate student needs special/extra help?
    - *If you did,*
        - How did you decide when a student needs special/extra help, and what kind of help was provided?
        - What kind of help was provided for the student?
    - *If the student is a non-native speaker,*
        - What did you feel the student's needs for engineering instruction?
    - *If the student is a female,*
        - What did you do to feel her needs for engineering instruction?
        - What kind of help/needs for the girls must be provided for the future class?
        - How did the girls/boys approach the class activities?
        - Did you observe anything interesting or out of the ordinary among the boys and girls?
        - What was your general observation of how the girls engaged in comparison to boys?
        - Is there a home advantage? Did students come into your classes with different levels of knowledge?

Question	**Teacher Debrief Related to the question**
1	4
2	1, 4
3	4
4	3, 4

Note
* 1 overlaps Section C: Knowledge of/attitudes toward/beliefs about pedagogy.

Priorities
2 > 1 > 4 > 3

Section C: Knowledge of/attitudes toward/beliefs about pedagogy

1. How did you determine to employ instructional activities in each EiE unit?*
    - Which activities in the EiE units were particularly successful?
2. Did you add any additional activities in any EiE unit? **
    - *If you have added,*
        - What activities have you added? How and why?
3. Did you skip any activities in any EIE unit? ***
    - *If you have skipped,*
        - What activities have you skipped? How and why?
4. How did you determine to intervene student activities to develop their concepts of engineering design process?
5. What kind of indicators did you use to gauge your effectiveness in teaching the EiE units? [e.g., posing open-ended questions, reading and commenting on the reflection students have written, asking students to explain concepts to one another, etc.]
6. What your students have learned from engaging in the engineering activities? [E.g., principles, concepts, or skills, etc.]
    - What kind of evaluation was effective in assessing such students' learning? Why do you think so?

Question	Teacher Debrief Related to the question
1	3, 4
2	1, 4
3	1, 4
4	4
5	3, 4
6	4

Note
* 1 overlaps Section A: Knowledge of/attitudes toward/beliefs about the subject matter and Section D: Pedagogical content knowledge/expertise.
** 2 overlaps Section A: Knowledge of/attitudes toward/beliefs about the subject matter.
*** 3 overlaps A: Knowledge of/attitudes toward/beliefs about the subject matter.

Priorities
1 > 4> 5, 6 > 2, 3

Section D: Pedagogical content knowledge/expertise

1. What resources did you use to plan instruction?
    - If you have questions or problems in implementing instruction of the EiE units, where and who do you go for help?
2. What kind of indicators did you use to gauge your effectiveness in integrating other subjects such as mathematics/science and literacy into the EiE units?
3. How did you integrate science, math, and literacy into your instruction?

- How did you incorporate the use of technology into your practice?
- Do you think that all the students in your class integrated mathematics/science into learning engineering?
  - If yes, why do you think so?
- Do you think that mathematics/science content was appropriate for your students?
  - If yes, what was your emphasis? [E.g., learning basic science concepts, learning important terms and facts of science/mathematics, learning science process/inquiry skills, etc.]

4. What did your students construct knowledge of engineering? [E.g., learning how to communicate ideas in engineering effectively, learn about the applications of engineering in daily life, learn about the relationship between science, technology, and society, learning to evaluate engineering products based on designing engineering process.
5. To what extent did you show a solid grasp of the subject matter content in the EiE units?

Question	**Teacher Debrief Related to the question**
1	1, 3
2	1, 4
3	1, 4
4	4
5	4

<u>Note</u>
N/A

<u>Priorities</u>
4 > 1 > 3> 2, 5

Section E: Choices about professional development, conferences, networks

1. What you think you have learned from participating Summer Academy?
   - Which parts of Summer Academy have been most helpful?
   - *If you ever participated Summer Academy before,*
     - Compared to previous year, which parts of Summer Academy are better than previous one?
     - How would you like Summer Academy to be different this year in order to better meet your needs?
     - If you were to redesign, which parts of Summer Academy you would like to redesign? Why do you think so?
2. What kind of support do you want to have on online professional development website?
   - Under what situation you want to seek help from online?
   - How long is it ok for you to get feedback?
   - How much time did it take you to formulate the question for posting online?
   - Please, describe the overall impact of your post and responses from online community in your problem solving process.
   - Please, estimate the problem solving time you saved due to the answers? (minutes)

3. Do you feel that your district administration is supportive to engineering education in any way?
4. What resources are available to you in planning instruction or for classroom use? [e.g., museums, local experts, videos and print materials, web sites]
5. What resources are available to your students if they need assistance to more elaborate concepts of engineering or design of engineering process? [e.g., Siblings, visiting engineering company programs, videos]

Question	**Teacher Debrief Related to the question**
1	N/A or ?
2	N/A or ?
3	N/A or ?
4	N/A or ?
5	N/A or ?

<u>Note</u>
N/A
<u>Priorities</u>
?