AC 2012-4068: UNDERSTANDING THE BELIEFS AND PERCEPTIONS OF TEACHERS WHO CHOOSE TO IMPLEMENT ENGINEERING-BASED SCIENCE INSTRUCTION

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Understanding the beliefs and perceptions of teachers who choose to implement engineering-based science instruction

In order for universities and schools to design K-12 engineering programs for maximum adoption and benefit, it is helpful to understand the beliefs of the teachers participating in the study, as well as what characteristics of a program make it worthwhile from the participating teachers' perspective.[1] Therefore, we conducted research on the aspects of an engineering-based science curriculum program that were beneficial from the teachers' viewpoint, as well as the teachers' beliefs about science teaching in general. We collected data through application and background surveys at the inception of the program and a focus group and online survey at the conclusion of the program. The purpose of this paper is to present what we learned about the self-efficacy of the participating teachers, about the affordances of the curriculum as viewed through the teachers' eyes, and about the teachers' perceptions of their students' learning.

In other manuscripts,[2,3] we have reported on our analyses comparing test performance of our engineering-based science students to that of students using their district's *status quo* curricula. Stated very briefly, the basic finding of those analyses was that the increase in science content score from pre-to post-test was significantly greater for the engineering-design-based students than for the comparison students. Other studies by our research team found that the engineering-design-based students demonstrate improved science practices and increased complexity of scientific reasoning.[4,5]

In this paper, we begin by reviewing previous research on teacher beliefs in relation to curriculum enactment and student learning, and then we describe the engineering-based science curriculum at the center of this study. Next we outline our specific research questions and describe our participants and data collection methods. We then present the results in terms of science teaching self-efficacy, perceptions of program affordances, and perceptions of changes in teaching and learning. We discuss implications for the recruitment of future participants for engineering-based curriculum interventions, and we consider the sustainability of such interventions after the completion of formal research programs. Finally, we suggest directions for future research on the changes over time in teacher characteristics and perceptions when they participate in K-12 engineering programs.

Previous Research

Studies since the 1950's have attempted to capture exactly what teacher characteristics have the most impact on student learning,[6] but despite a multitude of research, the question remains open. Our review of the literature on the impact of teacher characteristics, such as age, gender, undergraduate and graduate education, and certification status, found little evidence for the effect of these characteristics on student performance, especially in the elementary-school setting.[7,8,9] However, researchers continue to pursue links between teacher characteristics and student performance, in part because analysis shows that performance is statistically variable from teacher to teacher, even if there is no observable correlation between the characteristics of those teachers and student success.[10] This has prompted some to look beyond easily observable characteristics and instead focus on teachers' pedagogical content knowledge,[11] and knowledge of content and students.[12]

Another line of work has considered the beliefs teachers hold about the nature of science and how students learn.[13,14] One set of beliefs that is not directly observable is self-efficacy. Self-efficacy can be defined as "people's beliefs about their capabilities to produce designated levels of performance that exercise influence over events that affect their lives."[15] In general, people with high self-efficacy, rather than avoiding difficult tasks, look to them as challenges to be surmounted and skills to be mastered. This is relevant in the classroom, where it is thought that teachers with low self-efficacy may avoid developing better practices in exactly those areas in which they need the most improvement.[16,17] Additionally, teachers who believe in the efficacy of their teaching on student learning have a profound effect on their classrooms, exhibiting longer-lasting confidence and persistence, offering more productive feedback, and providing better academic focus.[17,18] Self-efficacy can be measured for different subjects, so that a teacher who exhibits low self-efficacy for teaching English may have higher self-efficacy for teaching science, and even one's self-efficacy toward learning science and teaching science may differ.[19] Along this reasoning, Riggs developed an instrument to measure specifically elementary school teachers' beliefs of their own efficacy in teaching science, called the Science Teaching Efficacy Belief Instrument (STEBI).[20] Results from this instrument could be used to help build teachers' self-efficacy for teaching science and to target instructional approaches for teachers to address their perceived weaknesses.[21]

Another indirectly accessible characteristic of teachers that may influence their students' success is their set of beliefs about the nature of science and the teaching of science. Drawing on the same principle as self-efficacy studies, that teachers' beliefs have a direct effect on their behavior in the classroom,[21,22,23] teachers' beliefs about how children learn science can alter their experiences and filter the strategies they take away from teacher professional development program.[24] These beliefs are then responsible for guiding teachers' behaviors that influence how successfully their students learn. Because teacher beliefs can be resistant to change,[25] it is important to discover what beliefs teachers hold before beginning a professional development course in order to plan effective interventions.[22,24]

For effective science teaching, research supports curricula that incorporate a variety of strategies to maximize student learning through experience. These strategies include reflection in student science journals,[26,27,28] authentic practices such as science process skills and the engineering design process,[29,30,31,32] motivation and engagement through goals that are personally meaningful to students,[33,34] and the active building of ideas through physical artifacts and models[35,36] All of these strategies are integral components of our program's engineering-based science curriculum, but the success of these strategies in the classroom largely depends on their faithful adoption by teachers. And teacher adoption of the strategies depends on the extent to which teachers perceive them as superior approaches to encourage student learning. Ideally, teachers' current beliefs would already exhibit many progressive characteristics and support building toward the ideal beliefs presented in the professional development. This would allow for small, manageable, and sustainable shifts in practice.[22,24,37]

Project Background

Our program's engineering-based science curriculum was designed to be enacted in third and fourth-grade classrooms with four different units: properties of materials, sound, simple machines, and animal structure and behavior. The units were designed to align with the national standards from the American Association for the Advancement of Science (AAAS) and the National Research Council (NRC),[38,39] as well as the Massachusetts state curriculum framework and the science-content needs of the participants' schools. While many middle and high-school problem-based curricula feature a design challenge of some kind, at the elementary level engineering design is often an ancillary subject, and is often only a supplement to science or social studies lessons.[33,34,40] The engineering-based science units in our research were intended to replace existing science units, and they incorporated inquiry and science content within the framework of a grand engineering-design challenge. These challenges included building a sturdy and insulated model house (properties of materials), designing a musical instrument (sound), constructing a people mover for an airport (simple machines), and creating a model of a rainforest animal (animal structure and behavior).

Methods

Research questions. This paper is the first from our research program to focus exclusively on the teachers involved in the project and their perceptions and experiences in implementing engineering-based science units. Three questions will be examined in this context:

1. What are the backgrounds and beliefs of teachers who piloted an engineering-based elementary science curriculum?
2. What materials, techniques, and curriculum approaches introduced in the training and intervention were deemed most important by the teachers?
3. How do the teachers think their practice of teaching science in the classroom was impacted by their participation in the program, and what differences in student learning do they think occurred as a result?

The first question will be explored mainly through the participants' application surveys, as well as the STEBI. The second and third questions will be answered using data from the focus group as well as curriculum-specific questions from the online survey. We are aware that self-reported data is limited and potentially biased, and that fully addressing the teacher characteristics beyond *perceptions* and *beliefs* would have involved measures of pedagogical content knowledge of knowledge of content and students.

Participants. The participants in this study were thirty-one elementary school teachers whose classrooms represented both diverse, urban populations as well as more homogeneous, suburban ones in a variety of public, charter, and parochial schools. All but one of the participants were female, and all but one taught in third or fourth grade classroom (see Figure 1). The average years of teaching experience upon applying to the program was 18.3, with a range of one year to thirty-seven years (see Figure 2). The teachers could choose to participate in the research program by enacting any or all of the four units (see Figure 4).

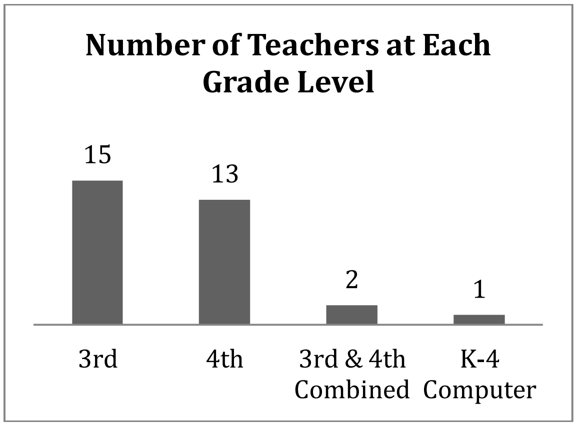

Figure 1

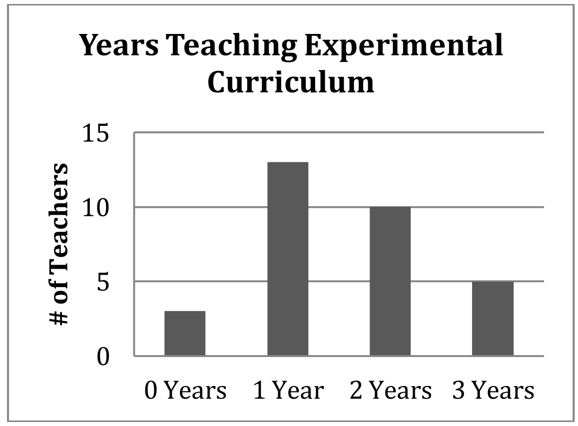

Figure 3

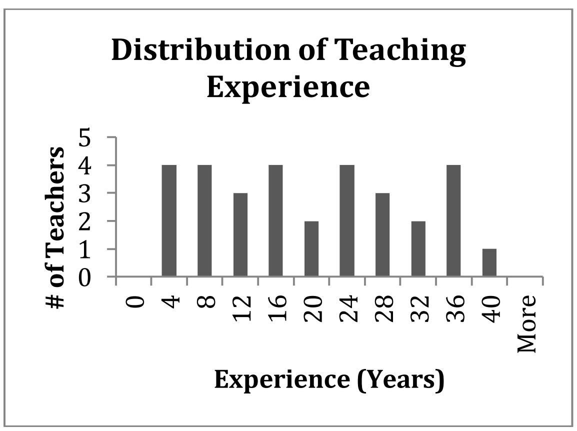

Figure 2

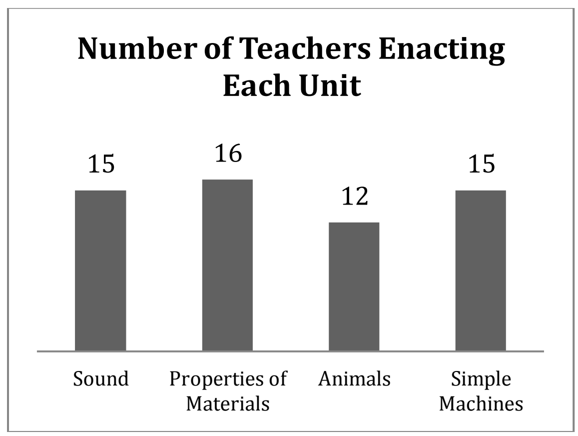

Figure 4

Implementation of the curriculum. Before their first year teaching the experimental (engineering-based) curriculum, each of the teachers participated in a week-long, summer workshop focused on the curriculum units they would enact in their classrooms the following school year. In addition to addressing the units' big science ideas, the workshop emphasized the engineering design process and ways to introduce and incorporate engineering in the teachers' classrooms. During these workshops, teachers played the role of students, working through each lesson with its associated engineering design challenges. This strategy was employed both to familiarize the teachers with the instructional materials, such as the student journals and the construction materials, as well as to model best practices in enacting the curriculum. Teacher ratings of this professional development experience were very high, and teachers generally felt more confident in their ability to teach the units after this experience according to surveys administered at the end of each workshop. The teachers received a stipend and professional development points for participating in the program.

Following their professional development, teachers enacted the curriculum at whatever point in the school year was most convenient for them. During their first year teaching the experimental curriculum, the teachers received two hours of classroom support per week. These paid classroom helpers, undergraduate or masters students in a variety of disciplines, were trained in the curriculum and assisted the teachers in many capacities, including one-on-one student assistance, technical support with the construction materials, and lesson preparation work. After the first year, the teachers received optional support for two, one-hour blocks for each unit they enacted. For all years, graduate student researchers served as liaisons for the teachers, checking in regularly by phone, email, or through classroom visits. In this way, teachers had many levels of support for enacting the curriculum and learning the new technology associated with it.

Data collection and analysis. Data were collected from three different sources: (1) the teachers' applications and background surveys from their initial acceptance into the program, (2) a focus group session at the conclusion of the program, and (3) an online survey at the conclusion of the program. The items on the applications and surveys took on several forms, including multiple-choice questions, questions requiring numerical answers (such as years teaching or current grade level), and open response questions. The hour-long focus group was moderated by two researchers, who asked teachers to share their opinions about several different topics relating to the experimental curriculum. For the written and verbal discussions, the results were coded using an open coding method first to identify themes,[41] and then the constant comparative method to consolidate them.[42] Sample survey and focus group questions are included in the appendix.

Data Source		Application and Background Survey	Focus Group	Online Survey (with STEBI)
Number of Participating Teachers		29*	6	13**
Years Teaching Curriculum	3	5	1	3
	2	10	1	5
	1	13	4	5
Units Taught	Sound	15	4	8
	Prop. Mat.	16	4	7
	Animals	12	3	6
	Simp Mach.	15	3	5

Table 1. Years spent teaching the experimental curriculum and units taught for the teachers represented by each data source. *One of these teachers had not yet completed the experimental curriculum. **Of the 13 teachers who completed the online survey, only 12 of the teachers completed the STEBI.

Results

Question #1: What are the backgrounds and beliefs of teachers who piloted this engineering-based science program?

Teacher participants' educational experience. Because much of the demographic information collected in our applications has been shown to have little impact on teaching success, we focused instead on the teachers' educational experiences, in order to explore whether the success of the teachers in our program was related to previous professional training in STEM education. Of the 21 responses to this question, all of the undergraduate degrees except 6 were in education majors, and all of the masters degrees were in education (see Figure 5), generally with a focus in elementary or early-childhood education. Only two of the teachers had STEM-related education degrees, one master of education in internet technology and one master of mathematics education. This indicates, and was confirmed by a separate question on the teacher background survey, that the teachers involved in this study largely entered the teaching profession through traditional teacher preparation programs, either at the undergraduate or master's level, and were licensed to teach elementary grades in the state of Massachusetts. When surveyed specifically about their science experience in college, most of the teachers answered that they took only the required number of science courses in college. However, 5 of the teachers took more than the required number of science courses, with the one psychology major self-reporting as a science major (see Figure 6). When asked for their comfort level teaching science, the most common teacher response was "moderately comfortable", a 2 on a scale with 1 as very comfortable and 5 as very uncomfortable. Their comfort level using educational computer software was higher (the mode response was a 1, "very comfortable," on the same scale). Teachers were also surveyed about their experience with the major technological tool used in the experimental curriculum, LEGO™ building sets (see Figure 7). Most teachers reported experience with LEGO™ during childhood or through playing with children, and over a third of teachers reported experience using LEGO™ in the classroom. Only one teacher reported no experience with LEGO™, and one teacher, a technology specialist, had actually been using LEGO™ robotics kits in her classrooms for several years. These answers indicate that the teachers in our program were generally familiar with LEGO™ as a toy, but not necessarily as a tool for engineering in the classroom, and were possibly more comfortable with educational computer software. All of the teachers had at least the requisite amount of science for an education degree, and while a few had coursework beyond that, our sample of teachers did not have much, if any, specialization in a STEM field or STEM education.

Teacher participants' self-efficacy. The Science Teaching Efficacy Belief Instrument (STEBI) a twenty-five question, Likert survey, was included in the final online survey sent to teachers at the conclusion of the research program. Response choices on the survey range from strongly disagree (1) to strongly agree (5), and the instrument is designed to measure two dimensions of teacher beliefs: science teaching *self-efficacy* and science teaching *outcome expectancy*. Teaching self-efficacy belief is the degree to which the teacher believes she possesses the skills necessary to teach effectively, while teaching outcome expectancy represents the degree to which the teacher believes she can affect the level of achievement of her students during lessons.[16,17] Studies by Markel, and Riggs and Enochs have verified the construct validity and stability of the STEBI instrument.[21,43]

The results from the twelve teachers who participated in the STEBI portion of the online survey showed very high self-efficacy belief and teaching outcome expectancy. Although these teachers made up a sample of only one third of the teachers in the research project, they were representative of a wide range of teaching styles, personalities, and success-levels within the program.   For twenty-four out of the twenty-five questions on the survey, the most common response was the second most self-efficacious category. The exception was the question, "*When teaching science, I usually welcome student questions,*" for which the most common response was the most self-efficacious category. The complete STEBI results can be seen in Tables 2 and 3 in the appendix.

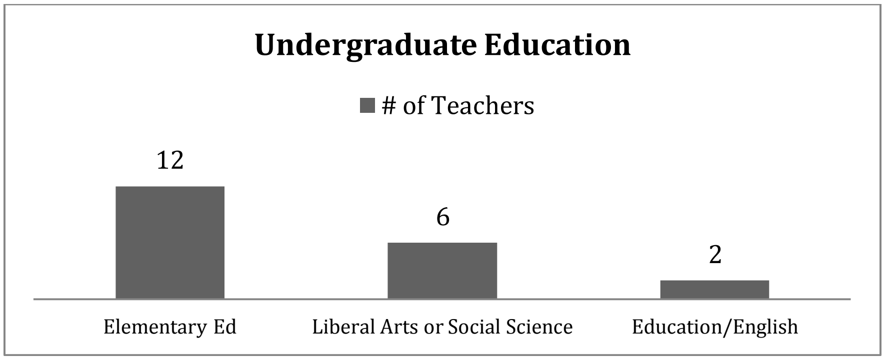

Figure 5

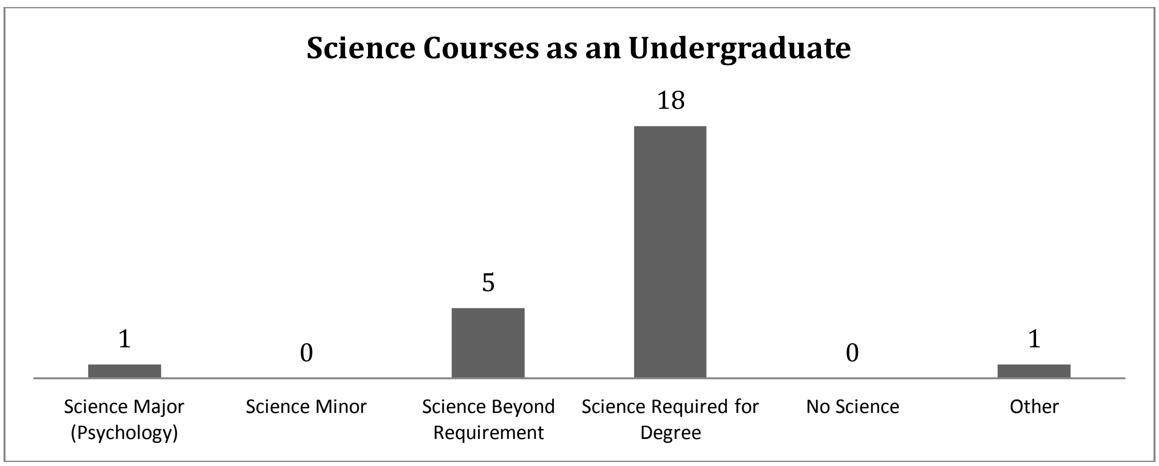

Figure 6

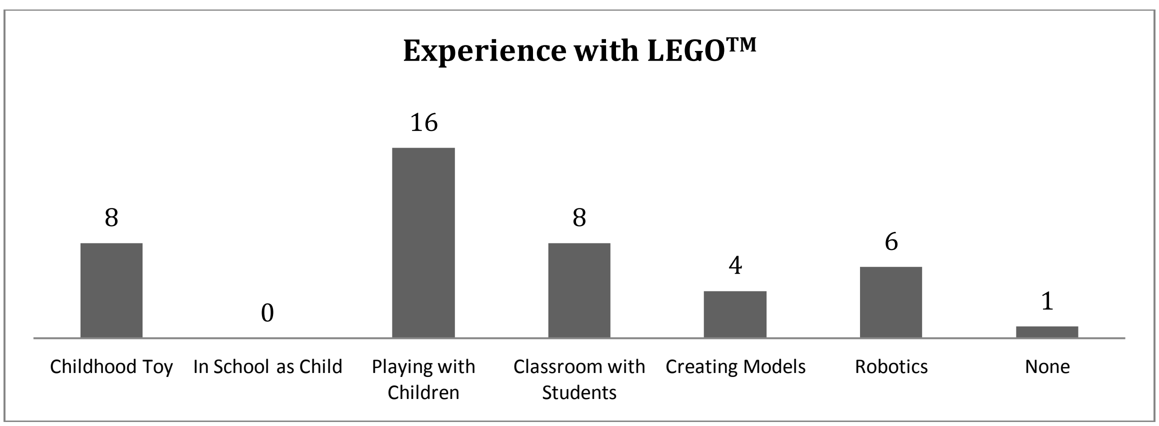

Figure 7

Question #2: What curriculum characteristics did the teachers perceive as important and as supported by our program?

Before implementing the experimental curriculum, teachers were asked on the background survey to identify their most and least favorite science topics (or units) to each and explain why. We found no clear trends in these data; some teachers rated a unit like electricity as their favorite while the next teacher would rate electricity as their least favorite. What did emerge in common among the teachers' responses was a set of themes about the practice of teaching those science units; student enthusiasm for a unit was cited as a reason for liking a unit, and classroom management issues were cited as a reason to dislike a unit, while three themes—hands-on activities, curriculum affordances, and the teachers' personal knowledge—were cited as both reasons to favor and not favor a unit (see Figure 8). These themes returned in the focus group interview, recurring in the specific characteristics of the experimental curriculum that teachers identified as being most important. For instance, the focus on building and the use of LEGOs satisfied the teachers' desire for "hands-on" learning experiences, while the professional development workshops and ongoing support from staff and undergraduates helped teachers bolster their personal knowledge of the subject matter and develop effective classroom management.

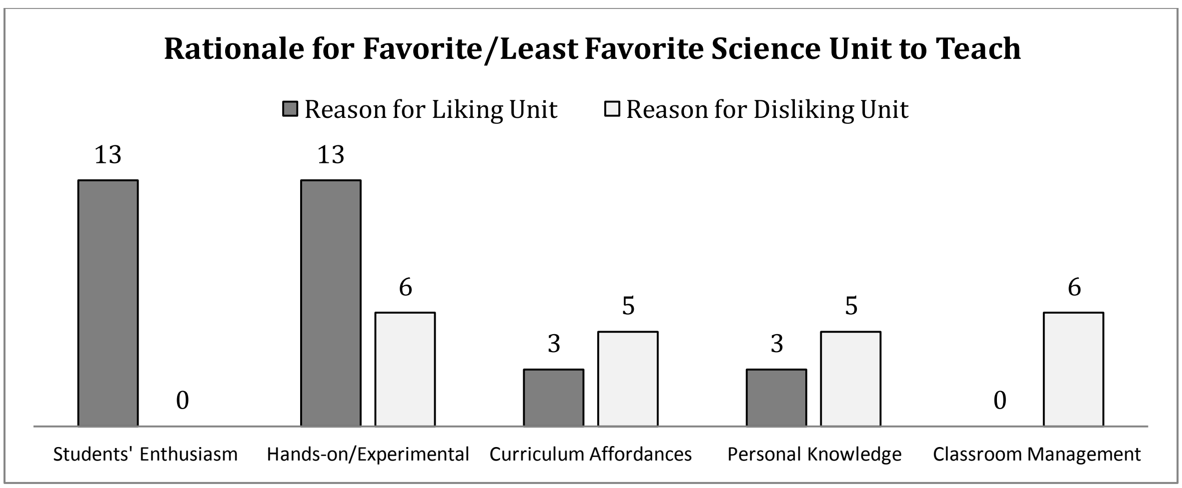

Figure 8

"Hands-on" learning. In the participants' discussion of their favorite science units to teach, one of the strongest themes was a unit's ability to incorporate hands-on learning. One teacher reported that she could not pick a favorite science unit because, "My favorite way to learn is to be engaged with materials in investigations and experiments." When mentioned in referring to least-favorite science units, the theme of hands-on learning was used to disparage units that were too traditional and lacking in tangible, inquiry experiences; another teacher explained that the solar system unit was her least favorite because it "tends to get boring. Too much reading, writing, and just talking. Not enough hands on." Hands-on learning was also mentioned several times as a general strength of science as a discipline, engaging children who normally would not excel in the traditional school environment. The second of two teachers unable to pick one single science topic as her favorite explained, "I enjoy teaching science because it is great to see those who usually struggle with ELA and Math excel. Students' enthusiasm for science is most often positive." This theme of hands-on learning was reiterated in the focus group and online survey at the conclusion of the research program. In particular, the "hands-on" nature of the experimental curriculum was mentioned as a positive factor in responses for every single unit in the experimental curriculum during the online post-survey.

LEGO™ materials. Specifically, LEGO™ materials were regarded as a positive aspect of the experimental curriculum. Many teachers mentioned how the concepts they were teaching, such as physical adaptations or sturdy structures, were aptly embodied by the LEGO™ elements; for instance, one class had previously been using clay to model animals which then dried with no moveable joints, as opposed to the functional LEGO™ models. The students' familiarity with LEGO™ building sets also led to increased student enthusiasm and confidence during science lessons, according to the teachers. The teachers preferred the LEGO™ kits over other materials, and they praised their simple maintenance and storage, the students' familiarity with their operation, the diversity of students' products, and the ease with which students could complete their design-challenge solutions, especially in the animals and simple machines units.

> *I think, too, the diversity of the LEGOs make it so that there's different solutions. And if you give only certain things, you know I watch them and the creative ways that they extended things. So I think that with the diversity of the pieces, it also gives that ability, to be able to come up with your own way of making things. It's not as restrictive, I think.*

The teachers reported that the LEGO™ construction kits provided scaffolding for teaching. For example, in the online post-survey, one teacher who had never taught simple machines before reported that using the kits reduced her anxiety. The physical materials supported her own knowledge and reasoning about simple machines.

Unit coherency. The teachers believed that the experimental curriculum was well structured and coherent for the students, which contributed positively to their understanding of the content material. For instance, one of the teachers stated:

> *I think that the coherency of the curriculum makes a huge difference compared to the regular kit, like the STC ® [Science and Technology for Children] animal kit compared to the LEGO™ kit, and they come out learning [with the LEGO™ kit] so much more about animals and how they function in habitats than they did before.*

Professional development. The professional development provided with the curriculum was another crucial element, according to the teachers. In the background survey, many teachers reported that they lacked sufficient content knowledge in topics like sound or electricity, or in general science process skills. The program's professional development provided teachers with tools, such as an educative teacher's guide, to overcome these perceived deficits. In the focus group discussion, one teacher described how she utilized the teacher's guides for the new units to familiarize herself with the science concepts before each class. She also believed the professional development workshop itself was instrumental to her success in teaching the units, and she voluntarily signed up for workshops on the remaining two units for the following summer:

> *The most useful thing for me was doing it last summer, the workshop. I think that without, and even then I forgot. But I think that if [the curriculum is] published there has to be some training.*

Real-time support. The classroom helpers provided by the project were also an integral part of how teachers implemented the unit. One teacher said the classroom helper made it much easier for her to manage teaching the unit for the first time, and she structured her class time around when the helper would be available in order to maximize her assistance with the LEGO^{TM} materials.

Student journals. Another tool introduced by the experimental curriculum was the use of student *Engineer's Journals,* which provided opportunities for students to share their prior knowledge about a topic at the beginning of a lesson, record data from investigations during the lesson, reflect upon new ideas at the end of a lesson, and plan for their execution of the design challenge. Beyond helping students organize their work, teachers found the journals helpful for organizing instruction. For example:

> *I mean for me [the journal] was just to organize me for the first time [teaching the unit]. And I just found that having the journal, we always knew what was going to happen next. And I think that was helpful.*

Question #3: How did teachers perceive teaching and student learning to change?

We now consider how teachers perceived the engineering-based science curriculum to have impacted their classrooms and their students' learning. These data can help us predict how teachers will implement the curriculum after the cessation of the research program.

Student engagement. According to the teachers, the engineering-based science curriculum increased levels of student engagement. In particular, the teachers spoke of the engaging nature of the hands-on construction activities with LEGO^{TM}. When shown test scores revealing that students in the experimental group gained more on the science content assessment than comparison students, one teacher cited engagement as a major factor.

> *I'm not surprised. I keep my students a lot more engaged with this lesson.*

Another teacher cited engagement as a source for better classroom behavior.

> *They pay attention more when they come to science when it was LEGO^{TM} time. They really pay attention and I was surprised because my kids, the minute they notice science time then they're, like, silent. They know.*

And, of course, the teachers believed that students perceived engineering with LEGO^{TM} as more fun.

> *Teacher 1: And the kids, we did the robots for the first time today, and they were, like, having so much fun learning.*
>
> *Teacher 2: Well I think one thing about it is that I think it engages student interest more than other materials would. [The students] do a sort of graduating or stepping up ceremony at the end of the year where my new students would come. And when my students who are staying [in the multi-grade class] tell them what we do, and one of the first things they say is, "we do LEGOs". And they don't say, "We do sound," they say, "We do LEGOs." And I can see some kids going, "Wow we really do LEGOs". And to find that the kids are really excited about it or they can't wait to get their hands on it.*

One teacher reasoned that the students learned more from the simple machines units because, due to the simplicity of the LEGO^{TM} materials, students were capable of setting up the gears and pulleys themselves, instead of relying on her to do it.

Student problem solving. Engineering played a much larger role in the experimental curriculum than it typically did in the teachers' classrooms before this research. Before enacting the curriculum, the teachers seemed less comfortable incorporating engineering than they did with educational computer software. However, once introduced to the engineering design process, some teachers seemed eager to emphasize the power of the design process for developing solutions to problems, and even likened it to the cycle already used to teach writing and revision.

> *You know what's happening now? We use the engineering process for everything. For math, you know it's the same kind of process no matter what we're doing, we seem to go through that engineering process and the kids see it. I mean, it's almost like that in writing, even though it's not related to that, but it's still sort of that same thing where, you know, you think of what your problem is, you try the possible solutions, and again that's something I knew nothing about. I love that, I mean there's still in my classroom all the [engineering] posters in there. And the kids really jumped onto that and there's a lot of engineer fathers and mothers in that classroom, too, so I know that there was a lot of positive feedback about it. Just the whole teaching that [engineering design process]. I even think I enjoyed that as well, the whole talking about what an engineer does, things I had never thought about before.*

Even with the addition of the new discipline of engineering, the teachers still felt like students were learning the required science content.

> *Well I think they learned the content very well because they could still organize it. They came out really knowing the basic knowledge, if not a little bit more.*

The engineering design process was not the only way teachers used the experimental curriculum to support students' problem solving and critical thinking. Many teachers found the prompts in the journal to be good starting points for critical thinking. One of the teachers explained this in the following way:

> *I think my class learned how to give evidence for their thoughts with the journals because we would have a discussion after, we'd sit in a circle and we'd talk about the lesson and the kids would bring their notebooks with them and I'd ask them a question about what we just did and when they'd raise their hand and give their answer I'd say, "How do you know that?" And at the beginning they would just look at me like, "Because we just did the lesson, you stupid!" But then I'd say, "Look at your notes, what does it say?" so they had to go back and prove what they know, with those journals. And that was really great. I think it sort of carried over into my reading lessons as well because you know the comprehension questions I'd say, "Well, how do you know that's the answer? Prove it." [inaudible] So it carries over across the subjects.*

Understanding the nature of science and engineering. As the previous quotation illustrates, the teachers saw their students developing personas as practitioners of science and engineering. Another teacher commented on helping students learn about the open-ended nature of science investigations and engineering challenges.

> *Well I think that when I did properties and materials with the third graders, I think they learned not only properties and materials but they learned a lot about experimenting. How to conduct experiments, how to have... and you know a lot of them kept saying, "Well what should the right answer be?" and I said, "Well you've got to find out what the right answer is, there is no right answer, just do the experiment and whatever comes out comes out."*

As we describe teachers' perceptions of student progress, it is important to note that the teachers also commented on times when they were not completely satisfied with their progress. Several teachers suggested that, in their future implementation of the lessons, they would incorporate supplemental activities and materials from their old curricula in order to support the new engineering-based science curriculum. This was especially common for the sound unit, where teachers wanted to incorporate more information about pitch from the Science and Technology for Children [STC] unit:

> *Teacher1: I've never taught the sound with the STC kits because I was immediately introduced to this, but there are one or two things that I want to pull out for some extra supplemental lessons to make sure, especially for students who have still trouble understanding.*
>
> *Teacher 2: I missed that whole tuning fork piece [from the STC kit]. And you know really just to see the vibrations through the tuning fork, so that's why I said there's a few things that, you know, I really did like because I mean they're going*

to see tuning forks so that was probably one of the things that I missed, that I didn't do.

Discussion

The results of this study show that our participating teachers believed that with the engineering-based curriculum, their students were more engaged in science instruction, more attentive to problem-solving approaches, and more aware of the open-ended nature of science and engineering. The teachers attributed the success of the engineering-based science program to its "hands-on" nature, LEGO™ materials, unit coherency, professional development, in-classroom support, and student journals. Many of these themes, such as “hands-on” learning and student enthusiasm for the materials and activities, echoed what the teachers said they valued in science curricula before participating in the program. This suggests that the teachers in our study already had views on the teaching of elementary science which agreed with reform efforts in science education, and this agreement may have supported a more faithful enactment of the experimental curriculum and an increased likelihood of the teachers continuing to use the curriculum after the program’s cessation.

The results of this study also show that the teachers who chose to participate in our engineering-based science program began the program with minimal science and engineering qualifications but ended it with highly efficacious beliefs about science teaching. Here it is important to note that we are not claiming evidence of a causal link between teachers’ participation in the engineering-based curriculum program and their highly efficacious beliefs about science teaching. The design of our study does not allow such a claim. In fact, given that the teachers volunteered to learn and implement a new science curriculum involving engineering and LEGO™ technology, it is likely that they began the study already possessing self-efficacy about their science teaching. However, we do think it is worth noting that teachers without a STEM background – even elementary teachers – can feel confident in doing engineering with their students.

What we see as the more interesting result related to the self-efficacy analysis is that the teachers scored higher on the science teaching efficacy part of the instrument than they did on the science teaching outcome expectancy portion. Somewhat paradoxically, while the teachers felt generally confident in their science teaching, at the same time many of them felt that their effect on student science learning outcomes was neutral. This is despite having participated in a research study that found their students to have made impressive gains on science content knowledge tests. Possibly the teachers had neutral outcome expectancy because they viewed science learning outcomes as mediated by many additional factors, such as student motivation, previous education, and support from home. However, we think that this finding has implications for how teachers are received into K-12 engineering outreach or professional development programs. What can be done to convince teachers of the strong link between their teaching practices and their students’ science and engineering learning? We could have engaged our teachers in a discussion of the research on the effectiveness of the science teaching strategies emphasized in our curriculum. By seeing evidence of those strategies’ impact on student science learning in other contexts, the teachers in our study may have increased their outcome expectancy within their own classroom contexts. This points to a question for further research: what influences a teacher's outcome expectancy when participating in a K-12 engineering program?

An important related question is whether our study's results suggest that the teachers will continue to incorporate engineering-based science into their teaching. What does the available data reveal about how likely the teachers are to continue using engineering-based science after the training, professional development, and institutional support is no longer available?

One finding that we view as related to this question is the teachers' interest in incorporating elements from their old science units into their subsequent enactments of the engineering-based curriculum. For example, recall that one teacher planned to integrate an investigation of tuning forks into the engineering-based unit sound when she next taught it. This desire to amalgamate the better parts of two curricula shows a reflective stance toward science teaching and a willingness to shift their practices toward what is most productive for their students. Teachers were also planning to use affordances of the engineering-based curriculum to modify their science units on other topics (not covered by the engineering-based curriculum). For instance, one teacher revised her rocks and minerals unit by creating student journals and incorporating tables and prompts that encouraged students to act as amateur geologists.

> *We've created a little rocks and minerals journal for the rocks and minerals [unit] that we do in third grade, and created a challenge the way that they did with this [engineering-based unit], where you kind of become an amateur geologist. At the end they ask the kids to identify some mystery minerals. I found that, I found it a little bit easier when I create some graphs and some charts to go along with it, which I thought they were lacking [in the existing rocks and minerals unit].*

Teachers also reported finding new uses for the LEGO™ tools in math class when teaching multiplication and geometry. Thus the teachers are attempting to *leverage* aspects of the engineering-based curriculum's instructional format (e.g., an overarching challenge, a student journal) as well as its physical materials (i.e., LEGO™) for other units of instruction, in math as well as science. We speculate that if the teachers are choosing to interweave the engineering-based science curriculum through their classroom in these ways, then they are likely to sustain the engineering-based approach even after the university support has ended.

Indeed, all of the teachers in the focus group were emphatic about continuing to implement the curriculum the following year, and our program continues to train new teachers in professional development workshops. We now need to consider how the program can capture the most essential elements of teacher support and training, those that encourage the adoption of appropriate beliefs supportive of a positive learning environment and promote the maintenance of the curriculum in classrooms, and present them efficiently to a larger audience.

Another avenue for future work involves administering self-efficacy and outcome expectancy instruments at the beginning as well as at the end of a K-12 engineering professional development experience, and designing modifications for the professional development based on the results of the pre-instruments. Information about teachers' self-efficacy and outcome expectancy might also be analyzed in conjunction with student learning outcomes. It would be fruitful to explore whether, when elementary school teachers incorporate engineering into their classrooms, there is a relationship between teachers' self-efficacy or outcome expectancy and student outcomes. If there is, what can be done to improve teachers' self-efficacy or outcome expectancy at the start of their participation in an engineering outreach or professional development program?

Conclusion

In this study we investigated the characteristics and perceptions of elementary teachers who voluntarily participated in an engineering-based science program. Our volunteer teachers were shown to be self-efficacious in their science teaching beliefs,[17] although somewhat less so in their teaching outcome expectancy beliefs.[21] Also, the teachers seemed to hold beliefs about the benefits of constructivist teaching methods before participating in the research project,[22] which may encourage their continued use of the engineering-based science curriculum after the program's cessation. The teachers saw the engineering-based science curriculum as successful, and they attributed its success to its "hands-on" nature, LEGO™ materials, unit coherency, professional development, in-classroom support, and student journals. The teachers revealed their perceptions that as a result of these program affordances, their students became more engaged in science instruction, more attentive to problem-solving approaches, and more aware of the open-ended nature of science and engineering.

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Appendix

	STEBI Question	High Efficacy/ Outcome Beliefs	Neutral	Low Efficacy/ Outcome Beliefs
1.	When a student does better than usual in science, it is often because the teacher exerted a little extra effort.	66.7	33.3	0
2.	I am continually finding better ways to teach science.	100	0	0
3.	Even when I try very hard, I don't teach science as	66.7	16.7	16.7

	well as I do most subjects. *			
4.	When the science grades of students improve, it is most often due to their teacher having found a more effective teaching approach.	75	25	0
5.	I know the steps necessary to teach science concepts effectively.	91.7	8.3	0
6.	I am not very effective in monitoring science experiments. *	91.7	8.3	0
7.	If students are underachieving in science, it is most likely due to ineffective science teaching. *	50	33.3	16.7
8.	I generally teach science effectively.	100	0	0
9.	The inadequacy of a student's science background can be overcome by good teaching.	83.3	16.7	0
10.	The low science achievement of some students cannot generally be blamed on their teachers. *	66.7	16.7	16.7
11.	When a low achieving child progresses in science, it is usually due to extra attention given by the teacher.	58.3	41.7	0
12.	I understand science concepts well enough to be effective in teaching elementary science.	100	0	0
13.	Increased effort in science teaching produces little change in some students' science achievement. *	66.7	25	8.3
14.	The teacher is generally responsible for the achievement of students in science.	58.3	33.3	8.3
15.	Students' achievement in science is directly related to their teacher's effectiveness in science teaching.	66.7	25	8.3
16.	If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher.	58.3	33.3	8.3
17.	I find it difficult to explain to students why science experiments work. *	66.7	16.7	16.7
18.	I am typically able to answer students' science questions.	83.3	8.3	8.3
19.	I believe I have the necessary skills to teach science.	100	0	0
20.	Effectiveness in science teaching has little influence on the achievement of students with low motivation. *	75	8.3	16.7
21.	Given a choice, I would not invite the principal to evaluate my science teaching. *	66.7	25	8.3
22.	When a student has difficulty understanding a science concept, I am usually at a loss as to how to help the student understand it better. *	100	0	0
23.	When teaching science, I usually welcome student questions.	91.7	0	8.3
24.	I don't know what to do to turn students on to science. *	100	0	0
25.	Even teachers with good science teaching abilities cannot help some kids learn science. *	58.3	41.7	0

Table 2. Results from the STEBI. Questions marked with an asterisk are written in the negative, so that response of "disagree" or "strongly disagree" denotes high efficacy. Shaded questions denote those questions that contribute to the personal science teaching efficacy belief, while unshaded questions contribute to the science teaching outcome expectancy. Adapted from Riggs and Enochs.[21]

	High Efficacy/ Outcome Beliefs	Neutral	Low Efficacy/ Outcome Beliefs
STEBI	77.7	16.7	5.7
Personal Science Teaching Efficacy Belief	89.1	6.4	4.5
Science Teaching Outcome Expectancy	65.3	27.8	6.9

Table 3. Average percentage responses for each measure of the STEBI

Excerpt from Application:

13. Describe the science units that you typically teach over the course of one year.
14. Describe the classroom management techniques that you use during science instruction.
15. What is your favorite science topic to teach? Why is it your favorite?
16. What is your least favorite science topic to teach? Why is it your least favorite?

Excerpt from Background Survey:

4. Science Lessons

How much time per week do you generally spend teaching science?
Do you teach more than one class science? If so, how many?
Are you a science specialist?
Rate your comfort level when teaching science lessons:

1	2	3	4	5
Very Comfortable	*Moderately Comfortable*	*Neither Comfortable nor Uncomfortable*	*Moderately Uncomfortable*	*Very Uncomfortable*

Excerpt from Focus Group Protocol:

Perceptions of students

1. What do teachers' think their students learned/how did they benefit?
2. Teacher's impressions of students' engineering process abilities – do they see changes? Struggle?
3. Did students need support for partner work? How was that support offered, if it was?

Excerpt from Online Survey:

1. How much do you enjoy teaching about animals?

(1) I really enjoy teaching about animals	(2) I often enjoy teaching about animals	(3) I feel neutral about teaching about animals	(4) I often do not enjoy teaching about animals	(5) I really do not enjoy teaching about animals

2. What impact do you think the LEGO Animal Model unit had on your students' learning?

(1) The LEGO Animal Model unit really helped my students learn about animals	(2) The LEGO Animal Model unit somewhat helped my students learn about animals	(3) The LEGO Animal model unit didn't help or hinder my students' learning about animals	(4) The LEGO Animal Model unit made it somewhat difficult for my students to learn about animals	(5) The LEGO Animal Model unit made it very difficult for my students to learn about animals

3. What did you feel was the strongest aspect or feature of the LEGO Animal Model curriculum?
4. What suggestions, if any, do you have for improving the LEGO Animal Model curriculum?