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Collaborations in a Community of Practice Working to Integrate Engineering Design in Elementary Science Education

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Abstract

The new standards for K-12 science education in the United States call for science teachers to integrate engineering concepts and practices within their science teaching in order to improve student learning. To accomplish this, teachers need appropriate instructional materials as well as the knowledge and skills to effectively use them. This mixed methods study examined participants' perceptions of a STEM education partnership project in which university faculty members and elementary school teachers collaborated to develop and implement engineering design-based materials in elementary science education. Quantitative survey results suggested that both university faculty members and participating school teachers demonstrated elements of collaboration characteristic of an effective community of practice, and qualitative data from open-ended survey responses and interviews identified the factors that participants viewed as important. Results suggest that collaborations among community of practice participants are important to the success of school-based STEM education reform initiatives like the one described here.

Keywords: K-12 engineering education, engineering design, faculty, teachers, community of practice

Introduction

In response to major national reports that have focused on the need to improve science, technology, engineering, and mathematics (STEM) education in the United States (National Academy of Sciences, 2007; National Science Board, 2007), a variety of reform initiatives have been launched to better integrate engineering and technology into traditional science and mathematics education in K-12 schools. *The Next Generation Science Standards* (NGSS Lead States, 2013), which are based on the *Framework for K-12 Science Education* (National Research Council, 2012), indicate that K-12 science education should be built around three dimensions: (1) scientific and engineering practices, (2) crosscutting concepts that unify science and engineering, and (3) core ideas from the disciplinary areas of physical science, life science, earth/space science, and engineering/technology. To achieve this vision for K-12 science education, teachers must be equipped with the knowledge and skills necessary to integrate engineering concepts and practices within their teaching, and they must have appropriate classroom curricular materials to introduce engineering concepts and practices to their students.

This paper describes a school-university partnership project designed to prepare elementary school teachers to integrate engineering design into their science instruction. As part of the project, university faculty members from the STEM disciplines worked together to create engineering-based instructional products, which, in turn, were used by participating school teachers to introduce engineering design to their students within the context of science teaching and learning. The collaborations of university faculty members and classroom teachers to produce and implement engineering-based instructional materials in the project draw on the notion of situated learning (Lave & Wenger, 1991) in which individuals become part of a community of practice, a group of people who share an area of expertise and learn from each other through interactions among group members. In the context of the project described in this paper, the idea of a community of practice can be applied both to the university faculty members, who worked together to develop engineering design-based instructional products, and to the broader community of teachers and faculty, which worked to implement design-based instructional products in the teachers' classrooms. This paper describes a mixed methods research study that examined faculty and teacher perceptions of the STEM education partnership project and the extent to which it demonstrated elements of collaboration consistent with an effective community of practice.

Research Questions

The research questions guiding this study were as follows: a) To what extent did university faculty members and teachers working on a STEM education partnership project perceive that the project demonstrated collaborative elements of a community of practice, and b) What elements of the partnership did faculty members and teachers identify as most important to the success of their efforts?

Background

According to the *Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*

> A coherent and consistent approach throughout grades K-12 is key to realizing the vision for science and engineering education embodied in the framework: that students, over multiple years of school, actively engage in science and engineering practices and apply crosscutting concepts to deepen their understanding of each field's disciplinary core ideas. (National Research Council, 2012, p. 2)

The new standards derived from the framework require that teachers, many of whom have had little or no experience with engineering, integrate engineering concepts and practices within their science teaching. How can this be accomplished?

The critical elements for successful implementation of the standards include curriculum, instruction, teacher professional development, and student assessment (National Research Council, 2012). Teachers must have appropriate curricular materials and the knowledge and skills to use them. Many in the scientific community have recommended that the school science curriculum be structured to utilize inquiry-based approaches focused on real-world contexts and pedagogical practices that help students develop the skills, knowledge, and abilities necessary for success in today's world. Various problem- and project-centered approaches have been developed that allow students to learn disciplinary content in the context of authentic problems (Carlson & Sullivan, 1999; Hmelo-Silver, 2004; Kolodner et al., 2003; Krajcik, Blumenfeld, Marx, Bass, & Fredricks, 1998). The engineering design process is one project-based approach that can be used to promote science learning (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005).

Teaching through engineering design has the potential to facilitate integrated instruction that meets the requirements of the new science education standards. Engineering design encourages students to construct refinable solutions to real problems using inquiry and cooperative learning processes that allow students to develop new understandings and to relate those understandings to other concepts (Mooney & Laubach, 2002). Design-based learning can help students develop scientific inquiry and real world problem-solving skills (Kolodner et al., 2003; Silk, Schunn, & Strand-Cary, 2009), enhance discipline-specific content knowledge and critical thinking skills (Doppelt, Mehalik, Schunn, & Krysinski, 2008; Hmelo, Holton, & Kolodner, 2000), and promote interest in science or engineering careers (Mehalik, Doppelt, & Schunn, 2008). During the design process, teaching and learning for understanding is emphasized (Fortus et al., 2005), and relevant science content is presented when needed and not treated simply as an "add-on" (Silk et al., 2009). The iterative nature of design-based learning provides learners with opportunities to address scientific misconceptions, devise and test new conceptions, collaborate with peers, and publicly present their findings (Kolodner, 2002). Students participating in design-based learning experiences have been found to be more motivated (Doppelt, 2003), learn more science content in comparison to classmates in traditional experiences (Kolodner et al., 2003; Doppelt et al., 2008), take more ownership for their own learning (Fortus et al., 2004), and develop improved scientific reasoning skills (Silk et al., 2009).

This study took place within the context of a project designed to introduce engineering design as a vehicle for science teaching and learning in the elementary grades. The Science Learning through Engineering Design (SLED) partnership project (https://stemedhub.org/groups/sled) is a large-scale, multi-year, targeted math-science partnership initiative supported by the National Science Foundation. The aim of the project is to increase grade 3-6 student learning of science by developing an integrated, engineering design-based approach to elementary school science education. Purdue University is the lead entity of the partnership, and project participants include faculty from the Colleges of Education, Engineering, Science, and Technology and as well as the Discovery Learning Research Center, an interdisciplinary research center. Four school districts in the state of Indiana, representing urban-fringe, suburban, and rural school communities, are partners.

One goal of the project is to adapt, refine, and test existing project- and design-based curricular materials/tasks and where necessary develop new ones to support the teaching of elementary science through authentic, inquiry-based, design projects. To achieve this goal, university STEM disciplinary faculty members participate in what are termed design teams, which work to create instructional products (activities and curricular materials) linked to state science standards and designed to utilize engineering design as a vehicle for student learning about relevant science concepts. The design teams develop the instructional products through a process that involves shared ownership of the problems the products are intended to address, refinement of the products through an iterative process involving small tests and changes, and shared ownership of the products deriving from multiple sources of innovation (Morris & Hiebert, 2011). The members of the partnership share the goal to help students learn science through engineering design. Refinement occurs through an implementation cycle in which teachers from the participating schools first test the design-team-created instructional materials during a teacher professional development summer institute, provide feedback to the design teams, and then implement revised materials in their own classrooms during the following academic year. The diversity of perspectives on the design teams, which include representatives from different STEM disciplines as well a classroom teacher, contributes to the multiple sources of innovation and shared ownership of the final products (Lehman & Capobianco, 2012).

By working together to develop engineering-based instructional materials and implement those materials in the classroom, the participants in the partnership, both university faculty and classroom teachers, may be viewed as a community of practice. Wenger, McDermott, and Snyder (2002) described a community of practice as a learning community consisting of "groups of people who share a concern, a set of problems, or passion about a topic, and deepen their knowledge and expertise in this area by interacting in an ongoing basis" (p. 4). A community of practice is compised of three elements: a domain, the community, and the practice. The domain, or area of interest, creates a sense of shared purpose, identity, and commitment among the participants. In this project, the participating STEM faculty and teachers shared a goal to create and implement standards-based curricular materials to integrate engineering design into the science curriculum and improve student learning outcomes. The community provides a framework in which participants can build relationships which encourage knowledge sharing, accountability, and promote interactions built on mutual respect and trust. The practice is the shared body of knowledge (i.e., standards, approaches, theories, rules, best practices, etc.) developed by practitioners in the community to inform their course of action.

Communities of practice have been discussed in the literature of many disciplines, including education, and have been identified as an important strategy for school improvement and professional development (Gajda & Koliba, 2007). While communities of practice are widely cited and often described in qualitative terms, Koliba and Gajda (2009) argue that there is a need for more research to better understand what leads to successful or unsuccessful communities of practice.

The success of communities of practice is "contingent upon both internal factors (the ability of CoPs members to collaborate) and external factors (how the CoP's activity connects to and supports organizational or network objectives)" (Koliba & Gajda, 2009, p. 115). An effective learning community fosters mutual respect and trust, creates a structure for individuals to share ideas and artifacts, and provides an environment for sharing and application of knowledge (Li et al., 2009). Erasmus (2005) noted that communities of practice may have the most impact on the norming and performing stages of Tuckman and Jensen's (1977) "forming-storming-norming-performing" model of team development when team members are acknowledging and accepting their roles, agreeing on a common goals and team ground rules, working collaboratively, and moving team activities towars completion of a task.

Facilitation of the collaborative work can also be an important part of effective communities of practice and may be linked to the success or failure of the group (Li et al., 2009). Facilitators may guide the day-to-day work of groups by leading team meetings, helping teams establish clear objectives and procedures, managing conflict, and establishing clear lines of communication with all team members (Burns, 1995). Facilitators may support community of practice work by assuming various roles including serving as an information source, inspiration, and guide (Tarmizi & de Vreede, 2005).

When examining school reform efforts, Gajda and Koliba (2007) linked communities of practice to a cycle of inquiry built around a shared purpose and involving dialogue, decision-making, action, and evaluation. In the context of school reforms, dialogue among community members centers around practice and its effects on student outcomes. Decision-making focuses on pedagogical practices and steps to be taken. Action is mutually agreed upon to address the goals of the community. Evaluation involves systematic collection and analysis of performance data to inform subsequent actions. These four elements provide a basis by which the effectiveness of communities of practice can be evaluated.

Research Methods

This study took place within the context of the Science Learning through Engineering Design (SLED) partnership during the 2012-2013 academic year. During this year, faculty design teams were engaged in developing engineering design-based instructional products for grades 3-4 for future implementation. Participating teachers were implementing instructional products for grades 5-6 that had been developed by design teams during the two preceding years of the project.

The study participants consisted of the university faculty members who were participating on the design teams and the teachers who were implementing activities in their classrooms. A total of 40 grade 6 teachers participated in the project, and there were three design teams, with a total of 10 university faculty members. Each design team consisted of 4 university faculty members, representing multiple STEM disciplines (e.g., engineering, science, technology). See Table 1 for a listing of the faculty members (pseudonyms are used), their disciplinary fields, and their year in the project. One faculty member on each team was identified as a team coordinator, who had responsibility for facilitating the team's efforts. In addition, a teacher from one of the partner school districts served on each team to provide a classroom perspective as the instructional activities were being developed. During the study, one team had two teachers who shared this responsibility.

Each design team developed two engineering design-based instructional activities during the academic year. For example, one design team created an activity and curricular materials related to constructing musical instruments for third grade students and then created a second activity for fourth grade students related to the design of door alarms. Each instructional activity was developed to use engineering design concepts to introduce science content aligned with state science standards for the respective grade level (e.g., for the door alarm activity, students learned concepts related to simple electrical circuits). The activities and accompanying lesson materials were developed during the academic year and pilot tested with teachers during the project's summer professional development institute, then revised by the design team, and subsequently integrated into classroom instruction by participating teachers.

During the development of the instructional materials, design teams met face-to-face about once every one to two weeks, on average, first to generate ideas for the materials and then to actually create them. Between meetings, members of the designs teams worked independently but stayed in touch with one another via e-mail. During the implementation of project activities, participating teachers often worked with one another in their schools. Teachers often met with one another to discuss project activities, and, in a number of cases, they co-taught lessons. Interactions between design team faculty and participating teachers took place in several ways. As noted above, each design team had a teacher representative who helped with the development of the instructional activities. In addition, during the project's summer institute, design teams introduced their instructional products to all of the participating teachers and spent a day working with them as the teachers tried out the activities. Finally, in a number of cases, members of the design teams and/or project staff went into teachers' classrooms during the academic year when the teachers were implementing project activities in order to provide support and assistance.

Both quantitative data and qualitative data were collected. Quantitative data consisted of faculty members' and teachers' responses to a partnership survey administered online in spring 2013, near the end of the academic year. The survey consisted of 30 five-point Likert-type items and five open-ended items. The first 24 Likert-type items of the survey were developed by the researchers to align with the Community of Practice Collaboration Assessment Rubric developed by Gajda (2006), which assesses communities of practice on four dimensions of collaboration. Nine survey items addressed dialogue (e.g., "Meetings with colleagues about the SLED project tend to have balanced participation from all"), six items addressed decision-making (e.g., "Decisions about SLED activities are fully informed by group dialog"), four items addressed action (e.g., "My work in SLED is intended to directly improve student learning"), and five items addressed evaluation (e.g., "My colleagues and I use evidence and not just anecdotal information to evaluate practice or make decisions"). The remaining six items addressed faculty members' and teachers' views of the SLED partnership and their roles in it (e.g., "I am confident in my ability to contribute to the SLED project"). Items were scored by assigning 5 points for a response of "strongly agree" down to 1 point for a response of "strongly disagree." Items within each category were averaged to provide an overall category score. A Cronbach Alpha reliability coefficient of .92 was calculated for the overall survey instrument. Reliabilities for each of the four dimensions of collaboration were calculated as .73 for dialogue, .79 for decision-making, .74

Team 1			Team 2			Team 3		
Pseudonym	Field	Year	Pseudonym	Field	Year	Pseudonym	Field	Year
Harry Brown*	tech	3	Brian Land*	sci	3	Mike Vance*	engr	3
Paula Adams	engr	3	Larry Jefferson	engr	1	Eric Davis	sci	3
Rene Thompson	engr	1	Ellen Keyes	engr	1	Howard Barrett	tech	2
Cathy King	tech	3						

* denotes team coordinator; field labels are engr = engineering, sci = science, tech = technology

Table 1. Faculty Design Team Participants

for action, and .75 for evaluation; the reliability of the items addressing participants' views of the partnership and their role in it was .75.

The qualitative data consisted of responses to open-ended survey items (e.g., "What factors in the SLED partnership do you think support your efforts?") as well as transcripts of semi-structured interviews conducted with design team members, midway through the 2012-13 academic year, and the teachers, at the end of spring semester 2013. The interview protocols included open-ended questions that allowed participants to share their perceptions of the project and their role in it. Qualitative data were analyzed through the lens of interpretative phenomenological analysis (Smith & Osborn, 2003). This qualitative research framework is concerned with how participants make sense of particular experiences or events that make up their personal and social world. In this study, we were focused on individuals' personal perceptions of their participation in the SLED partnership and their collaborations with others in the project. Open-ended survey responses and interview transcripts were read and re-read. Categories of responses were allowed to emerge from the data, and these were coalesced into themes related to the research question. Examples from the data are included in the results to illustrate the themes. Pseudonyms are used to identify all interview participants.

Results and Discussion

Research Question 1: To what extent did university faculty members and teachers working on a STEM education partnership project perceive that the project demonstrated collaborative elements of a community of practice?

A total of 8 design team faculty members and 32 teachers, 80% of each respective group, responded to the survey in the spring semester of 2013. Means and standard deviations of partnership survey categories for faculty members and teachers are displayed in Table 2. A mean of 3.00 represents neutral on the response scale, while means above 3.00 indicate agreement with category statements, and means below 3.00 indicate disagreement with the statements.

According to Gajda and Koliba (2007), communities of practice "engage in varying degrees of person-to-person communication, decision making, interdependent actions, and reflection on the efficacy of those actions in order to change practice and improve performance" (p 30). Based on responses to the survey, both design team faculty and teachers participating in the SLED partnership tended to agree with statements reflective of collaborative dialogue, decision-making, action, and evaluation. All of the means in Table 2 are above 4.00 (indicating agreement with corresponding survey statements), except for evaluation as rated by faculty (mean=3.65) which was more neutral but still indicative of agreement. These results suggest that participants in the SLED project perceived that the collaborations with each other were consistent with an effective community of practice.

Across most of the categories of survey items, the responses of university faculty and teachers were similar. Analysis of variance (ANOVA) revealed that there were no significant differences between faculty and teachers' perceptions except for the evaluation category ($F=6.675$, $p=.013$), where the faculty mean was significantly lower than that of the teachers. While the lower faculty mean could be indicative of collaboration issues related to the functioning of the faculty design teams, another explanation is that the faculty members were less involved in the systematic collection of evidence, which was the focus of the evaluation survey items, than were the teachers who implemented the instructional materials in their classrooms. The faculty design team members may not have perceived evaluation to be as important a component of their work as did the teachers.

Research Question 2: What elements of the partnership did faculty members and teachers identify as most important to the success of their efforts?

The qualitative data were used to address research question 2. Open-ended survey responses as well as interview data from participating design team faculty members and teachers were analyzed. Common themes emerging from the data, for both design team faculty members and participating teachers, are described below with supporting evidence.

Design Team Faculty Themes

For the design teams, the collaboration and teamwork of design team members was the most widely cited factor in the success of the design teams' efforts; 6 out of 8 design team faculty members who responded to the

Survey Category	Faculty (n=8) Mean (SD)	Teachers (n=32) Mean (SD)
Dialogue	4.10 (0.36)	4.02 (0.40)
Decision-Making	4.15 (0.27)	4.07 (0.52)
Action	4.25 (0.38)	4.34 (0.47)
Evaluation	3.65 (0.14)	4.09 (0.47)
Partnership Perceptions	4.29 (0.21)	4.29 (0.43)

Rating scale: 5=Strongly Agree to 1=Strongly Disagree

Table 2. Partnership Survey Category Means for Faculty Members and Teachers

survey cited team member collaboration as an important factor. For example, Eric Davis, a science faculty member, identified "collaborative problem solving design teams" as a key factor for success in an open-ended survey response. Brian Land, a science faculty member and design team leader, elaborated on the value of teamwork in a faculty interview, noting,

> There's a great deal of interchange and teamwork and very constructive discussion between the three different kinds of people: science, engineering and educator. That has worked well in terms of being willing to think about the different aspects of our goal… And each of us brings a little different perspective and a little different talent to that. And I think one of the things that's impressed me is that ability for our team… to listen to each other and to work as a team and to try to develop the best activity possible.

Mike Vance, an engineering faculty member and leader of another team, echoed this perception in an interview, saying,

> So in our team we have someone from biological sciences, we have one from… technology, and then we have a teacher from middle school. So I think they all bring different perspectives... So, for example… when I speak [the] voice that I hear is different compared to what you may be hearing… So those kinds of things help, having different kinds of expertise.

These responses suggest that the faculty members on the design teams valued the interdisciplinary collaborations that resulted from having individuals from different STEM disciplines on the teams. The knowledge, skills, and perspectives that different team members brought to the task of creating instructional products for the elementary classroom were perceived as helpful to the process.

As the comments above suggest, the importance of collaboration among design team members extended to the classroom teacher who served as a member of each design team; 4 out of 8 design team faculty members who responded to the survey cited teacher participation as important to the process. Paula Adams, an engineering faculty member, suggested, "The teacher participant is great at both contributing to the design task and also with keeping us grade-appropriate." In an interview, Harry Brown, a technology faculty member and team leader, commented that the teacher on his design team,

> …just kind of keeps everyone grounded for the particular grade level and understanding the teacher's point of view, the classroom's point of view. Without that we would probably be struggling… She's on the front line with those kids and understands where you have to hit with the level with the material.

These responses indicate that the university faculty members on the design teams viewed the participation of a practicing teacher as important to the collaborative work of the teams. The teacher contributed to the development of the instructional material, and played a unique role in ensuring that the materials being created were appropriate for the classroom and the students' ability levels.

Finally, team leadership was also identified as a theme among the design team faculty members; 3 out of 8 design team faculty members who responded to the survey cited the important of leadership. Paula Adams, an engineering faculty member, commented, "We have a great design team and team leader." Eric Davis, a science faculty member, discussed the role of his design team leader in an interview, saying,

> We have a new member of our team who is the designated leader, team leader. And, I think he's done very nice job of staying in a regular contact with all of the team members through email primarily… So, he does very nice job of reminding us what we need to do. And then when we were together, actually meeting in the team, I think he did a very good job of helping each of us figure out what our individual responsibilities will be for what we need to do between now and the time that we meet again in two weeks' time.

These responses suggest that the leaders of the design teams played an important role in managing the team's process of creating the instructional materials, for example, by maintaining communication among team members and helping to define team members' roles and responsibilities. This is consistent with previous research on the value of facilitation in communities of practice (Burns, 1995; Tarmizi & de Vreede, 2005).

Teacher Themes

For the participating school teachers, the most commonly cited factor in the success of their efforts in the partnership was access to the support provided by the design team faculty and the leadership of the SLED project; approximately 40% of the teachers responding to the survey identified this as an important factor. Opal Lisbon, a participating 6th grade teacher, responded to an open-ended survey question by writing, "The coordinators and Purdue affiliates have been more than helpful whenever I am in need of materials, advice, or help. This has made it much easier to implement tasks and gives me encouragement as well." Georgia Jones, another 6th grade teacher, noted, "I feel that the willingness and availability of the Purdue SLED team supports the comfort level of teachers to take extra risks to delve deeper into science and math concepts." In an interview, Malcolm Clark, a sixth grade teacher, commented that being a member of the SLED partnership meant

> …support. I mean, it truly does, because I have the opportunity to pull from individuals, the knowledge that they have about all of this. I mean, when you're talking to individuals who are in education and then individuals who are in engineering and technology. These are individuals that I can take from, their knowledge about something.

These results suggest that for the teachers, who had the challenge of implementing engineering design-based lessons but lacked prior experience with engineering, the ready availability of help from more knowledgeable members of the community was critically important. The support from the design team faculty and members of the project staff allowed the teachers to feel more comfortable in introducing what was for them new content and practices.

For many of the teachers, the design team-created engineering-based instructional materials themselves were also a key factor; approximately 30% of the teachers cited this as an important element in the success of their work. Veronica Henderson, a participating 6th grade teacher, identified the "already made lesson plans that can be tweaked to fit my curriculum" as something she found valuable. Tabitha Neilson, a 5th grade teacher, noted, "The lessons for each design task are easy to follow. Also, they allow for adaptions to be made as needed in my class." In an interview, Teresa Snyder, a 6th grade teacher, discussed the instructional materials saying, "I love the way that the lessons are put together. They're written in a way that a teacher can pick it up, and we can follow through the steps that have been well thought out." These responses suggest that, for the teachers, having flexible, ready-made curricular materials helped make their work possible.

Collaboration with other participating teachers was another important theme in the teachers' perceptions of what made the project successful; 25% of the teachers cited collaboration with school colleagues in their survey responses. Karen Carter, a participating 5th grade teacher, noted, "I work with an experienced and knowledgeable team of teachers. We work well as a team." Mary Miller, a 6th grade teacher, commented, "I think working with other teachers in the SLED partnership really helped. We were able to bounce ideas off one another to create an end result." In an interview, Harold Butcher, a 5th grade teacher, talked about how he and his colleagues worked together. He explained,

> We would sit down… we did a lot of lunches when we were doing different tasks… We'd make sure we were doing it all the same time so all 5th grade was doing the same design task at the same time, make sure we were on the same page…. And if we had questions we would try to figure it out together.

These responses indicate that collaboration among teachers, like collaboration among faculty, was important to the success of their efforts. Having the support of peers, as well as the support of more knowledgeable university faculty members, was a valued aspect of the community.

Conclusions and Implications

The results of this study indicate that the STEM disciplinary faculty members and practicing school teachers who participated in the SLED project functioned as collaborative members of a community of practice. Results from the survey of participants indicated that both faculty members and teachers agreed with statements aligned with Gajda's (2006) dimensions of collaboration in communities of practice: dialogue, decision-making, action, and evaluation. Across most survey categories, levels of agreement of faculty and teachers were similar. This suggests that the participants in the project perceived themselves to be engaged in an effective cycle of inquiry related to the development and integration of instructional materials designed to integrate engineering design in science teaching and learning in the elementary grades. STEM faculty members and teachers engaged in dialogue with one another related to their shared goals, participated in shared decision-making about their work, took actions to promote the aims of the project, and evaluated their efforts.

The qualitative data confirmed the importance of collaboration in the efforts of the members of the partnership to integrate engineering design in elementary science. The centrality of collaboration in this process is not a surprise. Koliba and Gajda (2009) noted, "Communities of practice are increasingly being utilized as an analytical framework to describe the dynamics of interpersonal collaboration and as an intervention strategy to promote organizational change" (p. 119). In this project, the community members worked together to change classroom practices through the development and implementation of instructional materials that integrate engineering and science and so address the new standards for K-12 science education.

Most of the efforts of the participating STEM university faculty members were directed at the development of instructional materials that were subsequently implemented in teachers' classrooms. During the development process, the faculty members worked together on design teams, first to identify a design-based activity to address particular elementary science learning standards and then to develop associated instructional activities and materials. The faculty members on each team represented different STEM disciplines and hence brought different knowledge bases and perspectives to the task. While interdisciplinary collaborations can be challenging because of differences in how individuals from different disciplines use terminology and see the world (Borrego & Newswander, 2008), the faculty members in this study viewed their different perspectives as a strength in developing the instructional products. These findings suggest that curriculum development efforts that seek to integrate STEM disciplines should draw on expertise from across disciplines.

In this project, the interdisciplinary collaboration was possible, in part, because the faculty participants valued the contributions of each other and were willing to work with one another to complete the task. The design team leaders assisted in this process by facilitating group processes. Effective interdisciplinary collaborations and successful communities of practice rely on participants' mutual respect and trust as well as effective group facilitation (Borrego & Newswander, 2008; Li et al., 2009).

The importance of collaboration on the design teams extended to a teacher representative who helped the design teams to develop activities that were grade-level appropriate for elementary students. While the STEM faculty brought content expertise to the task of developing the instructional products, most of the faculty members had limited knowledge of elementary education or what would be considered appropriate for students at the target grade levels. The classroom teacher on each design team was able to provide that important perspective. Partnerships involving classroom teachers and practicing scientists, who take on the role of content experts, have been proposed as a strategy that can facilitate the adoption of innovative classroom teaching practices (Loucks-Horsley, Hewson, Love, & Stiles, 1998). A successful partnership between teachers and scientists "requires that each value the knowledge and expertise of the other, recognize the importance of the roles played by each person, and begin to learn each other's work" (Loucks-Horsley et al., 1998, pp. 135-136). In this partnership, the STEM faculty members on the design teams valued the practical expertise of the classroom teachers, and the participating classrooms teachers valued the disciplinary expertise and content knowledge of the scientists and engineers.

For the participating teachers, the ability to access the expertise of the community during classroom implementation of the engineering design-based activities was a key factor in project success. The teachers benefitted from working with the university faculty when they were introduced to the engineering design-based activities during the project's summer institute, and in a number of cases, design team faculty and/or project staff members were able to go to teachers' classrooms during the academic year to assist with implementation of the instructional materials and model their use. The instructional materials, themselves, were also valued by teachers for providing the content in pre-packaged, easy-to-us, but flexible form that they could adapt to their own curriculum. In addition, teachers cited the value of collaborations with their school-based colleagues as they worked on the project. According to Li et al. (2009), "Communities provide a safe environment for individuals to engage in learning through observation and interaction with experts and through discussion with colleagues" (p. 3). For the teachers, most of whom had not previously been exposed to concepts related to engineering, the project community provided a support structure that allowed them to be comfortable in introducing new content and trying out a new pedagogical approach.

Increasingly, teamwork and collaboration are seen as critical to the solution of the complex and multi-disciplinary problems of today. Gajda and Koliba (2007) noted, "It is through interconnected communities of practice whose members are engaged in high-quality interpersonal collaboration that an organization learns to adapt, grow, and change successfully" (p. 27). In this study, the community of practice framework provided a useful lens for examining the interactions of a group engaged in STEM education reform. Aspects of a community of practice framework were used to examine the workings of both university faculty and classroom teachers, as well as the ways that those two groups intersected to create a larger community of practice. As this study illustrates, in the SLED project, STEM university faculty members and school teachers were able to effectively work together in a community of practice to address a common goal to create and implement engineering-based instructional materials to improve science teaching and learning. This approach may provide a model for how education in the U.S. can be transformed to align with the new national standards for science education.

Collaborative school-university partnerships represent one way to address national calls for the improvement of K-12 STEM education. In calling for an emphasis on both science and engineering knowledge and practices, the new national standards for K-12 science education challenge the entire educational system to change. If we are to be successful, we must find ways to collaborate to successfully make the changes required.

STEM faculty at universities can contribute to these reforms by joining the conversation and helping to define curriculum that effectively integrates engineering and science. In this project, STEM university faculty members from different disciplines were able to work together with practicing educators to create engineering design-based instructional products for elementary science teaching and learning. The participants on the design teams valued the diversity of perspectives resulting from having different disciplines represented. This suggests that we need to find ways to bring together faculty from different disciplines to address issues in STEM education. A challenge in making this happen is that the traditional university faculty reward structure tends not to place value on STEM faculty members' engagement in educational endeavors (Borrego & Newswander, 2008).

K-12 teachers and schools have the challenge of implementing the new standards in classrooms despite the fact that most teachers have little or no background or education in engineering. While flexible and effective curricular materials are needed, as this study demonstrated, teachers also need professional development and support in order to be able to implement engineering content and practices in their science instruction. In this study, support was provided by the community in the form of the university faculty, who contributed their content expertise, and peer teachers who supported one another's implementation efforts. For the STEM education community, a challenge is finding ways to scale up the collaborative elements of this project to effect change in K-12 STEM education nationwide. As the *Framework for K-12 Science Education* (National Research Council, 2012) suggests, we need more research on K-12 teachers' knowledge and teaching practices, effective professional development for teachers, and curriculum and instruction to effectively implement the new standards and improve STEM learning for all.

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References

Abell, S., & Lederman, N. (2007). *Handbook on research in science education.* Thousand Oaks: Sage.

Borrega, M. & Newswander, L. K. (2008). Characteristics of successful cross-disciplinary engineering education collaborations. *Journal of Engineering Education, 97*(2), 123-134.

Burns, G. (1995). The secrets of team facilitation. *Training & Development, 49*(6), 46-52.

Carlson, L. E. & Sullivan, J. F. (1999). Hands-on engineering: Learning by doing in the integrated teaching and learning program. *The International Journal of Engineering Education, 15*(1), 20-31.

Doppelt, Y. (2003). Implementation and assessment of project-based learning in a flexible environment. *International Journal of Technology and Design Education, 13*(3), 255-272.

Doppelt, Y., Mehalik, M. M., Schunn, C. D., & Krysinski, D. (2008). Engagement and achievements: A case study of design-based learning in a science context. *Journal of Technology Education, 19*(2), 22-39.

Erasmus, R. (2005). The impact of communities of practice (COP) on Inter-firm alliance research teams. DBL thesis. University of South Africa. Pretoria. Retrieved from http://uir.unisa.ac.za/bitstream/handle/10500/1453/thesis.pdf.

Fortus, D., Dershimer, R.C., Krajcik, J., Marx, R.W., & Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching, 41*(10), 1081–1110.

Fortus, D., Krajcik, J., Dershimer, R.C., Marx, R.W., & Mamlok-Naaman, R. (2005). Design-based science and real-world problem-solving. *International Journal of Science Education, 27*(7), 855–879.

Gajda, R. (2006). Utilizing the CoPCAR to evaluate professional learning communities: Implications for school improvement. Expert Lecture delivered at the American Evaluation Association Annual Conference, Portland, OR.

Gajda, R. & Koliba, C. (2007). Evaluating the imperative of intra-organizational collaboration: A school improvement perspective. *American Journal of Evaluation, 28*(1), 26-44.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235-265.

Hmelo, C. E., Holton, D. L., & Kolodner, J. L. (2000). Designing to learn about complex systems. *The Journal of Learning Sciences, 9*(3), 247-298.

Koliba, C., & Gajda, R. (2009). "Communities of practice" as an analytical construct: Implications for theory and practice. *International Journal of Public Administration, 32*(2), 97-135.

Kolodner, J. L. (2002). Facilitating the learning of design practices: Lessons learned from an inquiry into science education. *Journal of Industrial Teacher Education, 39*(3), 9-40.

Kolodner, J.L., Crismond, D., Fasse, B., Gray, J., Holbrook, J., & Puntembakar, S. (2003). Putting a student-centered Learning by DesignTM curriculum into practice: Lessons learned. *Journal of the Learning Sciences, 12*(4), 495-547.

Krajcik, J., Blumenfeld, P. C., Marx, R. W., Bass, K. M., & Fredricks, J. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school students. *The Journal of the Learning Sciences, 7*(3-4), 313-350.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* New York, NY: Cambridge University Press.

Lederman, N., & Niess, M. (1997). Integrated, interdisciplinary, or thematic instruction? Is this a question or is it questionable semantics? *School Science and Mathematics, 97*(2), 57-58.

Lehman, J., & Capobianco, B. (2012). Creating shared instructional products for integrating engineering education in the science learning through engineering design (SLED) partnership. Paper presented at the annual meeting of the Association for Science Teacher Education (ASTE), Clearwater, Florida.

Li, L. C., Grimshaw, J. M., Nielsen, C., Judd, M., Coyte, P. C., & Graham, I. D. (2009). Evolution of Wenger's concept of community of practice. *Implementation Science, 4*, 4-11.

Loucks-Horsley, S., Hewson, P. W., Love, N., & Stiles, K. E. (1998). *Designing professional development for teachers of science and mathematics.* Thousand Oaks, CA: Corwin Press.

Mehalik M. M., Doppelt, Y., & Schunn, C. D. (2008). Middle-school science through design-based learning versus scripted inquiry: better overall science concept learning and equity gap reduction. *Journal of Engineering Education, 97*(1), 71-85.

Mooney, M. A. & Laubach, T. A. (2002). Adventure engineering: A design centered, inquiry based approach to middle grade science and mathematics education. *Journal of Engineering Education, 91*(3), 309-318.

Morris, A. K., & Hiebert, J. (2011). Creating shared instructional products: An alternative approach to improving teaching. *Educational Researcher ,40*(1), 5-14.

National Academy of Sciences, Committee on Prospering in the Global Economy of the 21st Century. (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future.* Washington, D.C.: National Academies Press.

National Science Board. (2007). *A national action plan for addressing the critical needs of the U.S. science, technology, engineering, and mathematics education system.* Washington, D.C.: National Science Foundation.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states.* Washington, DC: The National Academies Press.

Silk, E. M., Schunn, C. D., & Strand-Cary, M. (2009). The impact of an engineering design curriculum on science reasoning in an urban setting. *Journal of Science Education and Technology, 18*(3), 209-223.

Smith, J. A., & Osborn, M. (2003). Interpretive phenomenological analysis. In J. A. Smith (Ed.), *Qualitative Psychology A Practical Guide to Research Methods* (pp. 53-80). London: Sage.

Tarmizi, H. & de Vreede, G. J. (2005). A facilitation task taxonomy for communities of practice. In *Proceedings of the 11th Americas Conference on Information Systems 2005, Omaha, Nebraska, USA*, (pp.3545–3554).

Tuckman, B. & M. Jensen. (1977). Stages of small group development. *Group and Organization Studies, 2*(4), 419-27.

Wenger, E., McDermott, R., & Snyder, W.M. (2002). *Cultivating communities of practice: A guide to managing knowledge.* Boston, MA: Harvard Business School Press.

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