[Journal of STEM Teacher Education](http://ir.library.illinoisstate.edu/jste)

Volume 50
Issue 1 *Fall*

Article 4

September 2015

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Journal of STEM Teacher Education
2015, Vol. 50, No. 1, 3–17

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Abstract

This article discusses the findings of a qualitative evaluation study of ninth and tenth grade CincySTEM ITEST projects that were designed and implemented in a new urban STEM high school. The projects were framed by project-based learning and 5E Learning Cycle principles and utilized digital backpack equipment. Many of the projects were pedagogically innovative and engaging. The study indicated that the keys to their success were teachers' accumulated experience, peer support, and professional development. The article concludes with the contributions of the study and the legacy of CincySTEM ITEST projects.

Key words: STEM education; project-based learning; urban high school STEM initiatives; digital backpacks; 5E Learning Cycle

Background

The 2008 recession amplified decades of poor academic performance among low-income students of color living in urban areas, as indicated on international assessments of achievement in science and mathematics, which are widely regarded as subjects that foster economic competitiveness (Drew, 2011). In response to this alarming trend and other educational and economic imperatives, the President's Council of Advisors on Science and Technology (2010) pushed for the "recruit[ment] and train[ing of] 100,000 great STEM teachers" (p. xi) and the creation of "1,000 new STEM-focused schools over the next decade" (p. xii). Several states

Acknowledgement

This material is based upon work supported by the National Science Foundation under Grant No. DRL-0929557. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

This manuscript is approved by the Cincinnati Public School District Research and Evaluation Office.

responded to this agenda through the allocation of funds to set up STEM schools, which would ideally be staffed by teachers with strong expertise in STEM subjects. In the state of Ohio, legislators authorized seed grants for the establishment of new STEM public high schools.

In March 2008, a partnership in Cincinnati involving the local public school district, higher education institutions, corporations, and other agencies secured one of the seed grants. The decision was made to transform an existing urban high school serving large numbers of low-income African American students into the new STEM school. A planning team composed of lead veteran teachers, the new school principal, and a university researcher developed a school vision that emphasized college readiness through project-based learning (PBL) pedagogy (Hemmings, 2012; Rhodes, Stevens, & Hemmings, 2011). The team identified PBL as the optimal approach because it is regarded as central to innovative 21st century STEM education (Krajcik & Blumenfeld, 2006; National Research Council, 2000, 2012). Research indicates that PBL is an especially good approach for STEM education because it engages students in investigations of authentic real-world problems (Brickman et al., 2012; Duran & Şendağ, 2012). The approach also enhances critical thinking, independence, and innovation (Barak & Asad, 2012; Fishman & Krajcik, 2003; Krajcik, Czerniak, & Berger, 2003) as well as collaboration and organizational skills through inquiring questions, data collection, analysis, and reporting (Beckett, 2006; Bell, 2010; Hung, Hwang, & Huang, 2012; Isbell, 2005). It affords opportunities for fostering effective oral and written communication, information gathering, assessment, and analyses as well as students' curiosity and imagination in STEM specific content knowledge (Wagner, 2008).

Hughes High School, the new STEM high school in Cincinnati, was opened in fall 2008. A year later in 2009, the school was awarded an Innovative Technology Experiences for Students and Teachers (ITEST) grant from the National Science Foundation (NSF) to fund the design and integration of PBL CincySTEM ITEST projects into ninth and tenth grade science, technology, and STEM Foundations classes. The grant funded the purchase of digital backpacks called F-SETs, each of which contains the following equipment: a Texas Instruments (TI) Inspire calculator, a Livescribe pen and notebook, a laptop, an iPod Touch, an iPad, a Sony Cybershot digital camera, a Kodak digital video camera, and various science probes. The F-SET equipment could be used in the classroom as well as off-site for data collection, documentation, analysis, and product generation. Five CincySTEM ITEST projects—Energy Kaizenator, Global Climate Change, Global Water Challenge, Human Genome, and Roller Coaster—were designed and implemented by teacher teams.

The projects incorporated PBL pedagogical practices and were also guided by 5E Learning Cycle principles grouped under questions related to engagement, exploration, explanation, elaboration, and evaluation. The 5E Learning Cycle, created by Karplus and Thier (1967) for the Science Curriculum Improvement Study (SCIS), is a research-based model that consists of a recursive cycle of learning based on constructivist learning theory (Poomsripanon & Chitramvong, 2006). It has been shown to improve students' overall understanding of science and science concepts (Balci, Cakiroglu, & Tekkaya, 2006; Kowasupat, Jittam, Sriwattanarothai, Ruenwongsa, & Panijpan, 2012) and help students clarify their thought processes and correct misconceptions (Balci, Cakiroglu, & Tekkaya, 2006). Students participating in inquiry science guided by the 5E Learning Cycle have demonstrated better scientific reasoning abilities and positive attitudes toward learning (Kowasupat, Jittam, Sriwattanarothai, Ruenwongsa, & Panijpan, 2012). Applications of 5E Learning Cycle principles can also make learning activities more interesting, fun, motivating, and instructionally conducive for higher order thinking (Boddy, Watson, & Aubusson, 2003). This is especially true for activities involving the internet and other e-tools. As Su, Chiu, and Wang (2010) discovered, "e-learning materials based on the 5E are more beneficial than e-learning materials without 5E" (p. 402).

The overall purpose of the CincySTEM ITEST projects was to engage ninth and tenth grade students in innovative PBL and 5E science projects utilizing F-SET backpack equipment and develop a website featuring the projects (http://hughescincystem.com). The projects were developed by teacher teams over the course of the 3-year grant period. Team members and other teachers who were not involved in design work integrated the projects into their science, STEM Foundations, and technology courses. A qualitative evaluation study was conducted to find out if the projects increased student engagement and promoted learning and if they could be sustained over time. Although some projects were observably successful, teachers in other projects encountered challenges that were difficult for them to overcome. These challenges are well documented in the literature. What was revelatory in the study was how crucial teachers' accumulated experiences, peer support, and professional development were to success.

Challenges of Project-Based Learning in STEM Instruction

The PBL techniques and 5E Learning Cycle principles applied in the CincySTEM ITEST projects directly address the call to educate more STEM competitive students. They are rooted in the American philosophy of pragmatism through unfettered inquiry and emphasize learning in authentic contexts as the best environment for bringing schooling and the real world closer together (Barron et al., 1998; Bernstein, 1998; Blumenfeld et al., 1991; Dewey, 1916/1966; Krajcik & Blumenfeld, 2006; Peirce, 1958). However, the literature on PBL suggests that teachers who attempt such an approach in public school classrooms often confront a number of challenges related to administration and classroom supervision, appropriate expertise, community support, and tradition (Hosic, 1918; Kilpatrick, 1918). These challenges are endemic and help explain why despite significant advances in cognitive science and the availability of innovative instructional models large-scale efforts to align classroom instruction with philosophically pragmatic and theoretically constructivist approaches like PBL have been ineffective (Barron et al., 1998; Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000; Cuban, 2009, 2013; Elmore, 1996; Sawyer, 2006). Howe and Berv (2000) point out that a constructivist view of learning does not neatly translate into a set of classroom practices. Those practices that do align with constructivist theory involve a radical change in teacher beliefs (Prawat, 1992). Transitioning to approaches like PBL involves incentivizing teacher change, respecting the complexities involved, and having reasonable expectations (Elmore, 1996; Towndrow, Silver, & Albright, 2010). From a pedagogical perspective, PBL must attend to real-world barriers experienced by classroom teachers as well as the manner in which teachers understand PBL practices. The success of PBL is dependent upon teachers' capacity and willingness to understand, enact, and sustain authentic PBL practices in context.

An insightful body of research relevant to PBL was conducted on an instructional innovation dubbed project-based science (PBS) that was developed and refined during a long-term collaboration between researchers at the University of Michigan and teachers employed in Detroit Public Schools. That research spans the last 15 years of the PBS initiative, which was based on an explicit model grounded in constructivist theory (Blumenfeld et al., 1991). It includes detailed case studies related to teachers' understanding and enactment of the model and frank discussions of the challenges encountered when the model was used as the basis for systemic and sustainable reform in urban schools (Krajcik, Blumenfeld, Marx, & Soloway, 1994; Ladewski, Krajcik, & Harvey, 1994; Marx et al., 1994; Marx, Blumenfeld, Krajcik, & Soloway, 1997). When the approach worked, as Marx et al. (2004) discovered in a 3-year study involving a large sample of urban middle school teachers and students, there were statistically significant gains in student learning that remained stable even during scale-ups. The Marx et al. study provides strong evidence that carefully orchestrated efforts at project-based pedagogical reform can work in urban settings. Other research indicates the use of technologies in science projects such as iPads and laptop computers can bolster achievement because it increases student engagement (Tinker & Krajcik, 2001). It is thus possible for science and other teachers in urban high schools to adopt a PBL approach that results in measurable student gains in learning and interest in STEM fields.

Research also shows that teachers need considerable support to successfully facilitate PBL. Regular meetings among researchers, content specialists, technology support staff, and teachers are critical to the effective enactment of project-based science (Blumenfeld, Krajcik, Marx, & Soloway 1994). This is particularly true for today's technology-intensive models (Boss & Krauss, 2007; Krajcik & Starr, 2001; Moursund, 2003; Uden & Beaumont, 2006), which necessitate professional development specific to technology integration (e.g. Higgins & Spitulnik, 2008; Mumtaz, 2000).

Krajcik et al. (1994) argue that teachers need to collaborate and to honestly communicate about the challenges they are experiencing related to classroom management and project implementation. Although such collaboration is time consuming, labor intensive, and can be expensive, it is the most effective avenue for building teacher capacity (Blumenfeld et al., 1994, 2000). Time for teacher collaboration becomes increasingly important whenever instructional innovations are the primary means for comprehensive school reform (Desimone, 2002). Even with such support, research suggests that teachers who enact PBS have difficulty managing a collaborative classroom and realizing the constructivist outcomes that such practices are theoretically expected to produce (Blumenfeld et al., 2000; Marx et al., 1994). These challenges are exacerbated by a variety of cultural barriers, management routines, and school or district policies that discourage collaboration, risk-taking, long-term assignments, and learning outside of the school building (Blumenfeld et al., 2000).

Case studies related to PBS also demonstrate that teachers enact PBS differently depending upon their beliefs about teaching and learning and their prior experience with educational innovations (Ladewski et al., 1994; Marx et al., 1994). In a case-based study of five teachers' reactions to a state-level reform in California's mathematics education, researchers found that some teachers changed their practice very much, some changed their practice very little, and some did not change their practice at all. The degree of changes depended upon teachers' beliefs and experiences and how they responded to the affective demands of managing an inquiry-based classroom (Cohen & Ball, 1990; Dreon & McDonald, 2012; Wallace & Kang, 2004). The teachers at Hughes High School confronted common challenges as they worked together to change how they taught and what they believed about teaching science through CincySTEM ITEST projects.

Implementation of CincySTEM ITEST Projects

With NSF-ITEST grant funding for F-SET backpack equipment and research-informed astuteness about the challenges associated with PBL, teams of teachers at Hugh High School proceeded to design and implement five CincySTEM ITEST projects—*Energy Kaizenator*, *Global Climate Change, Global Water Challenge, Human Genome,* and *Roller Coaster.* The projects were integrated into ninth and tenth grade science, STEM Foundations, and technology classes during the course of the 3-year grant. *Energy Kaizen,* the first project to be implemented, was designed to teach the fundamentals of energy audits and teach students how to identify energy kaizens in order to reduce costs and greenhouse gas emissions and improve operations in schools and homes. This project was piloted in spring 2010 by the two teachers who developed it and was implemented in spring 2011 in ninth grade by one returning teacher and one teacher who was new to the project. Both of these teachers implemented the project again in spring 2012 with minor revisions to improve its integration with the academic schedule, curriculum, and each instructor's teaching style. *Global Climate Change* focused on the causes and effects of global warming and how to develop an action plan designed to encourage the community to think globally and act locally. This project was implemented in fall 2010 by teachers who were new to the project. During the next year, one returning teacher took the lead and created more detailed course documentation to support the lessons and activities. The aim of the *Human Genome* project was to teach students the science of genetics and the social science of genealogy. This project was first taught in winter 2010–2011 by two teachers who were new to the project. When this project was implemented again in 2011–2012, the primary teacher was not in the school for the entire year due to a military deployment. The *Global Water Challenge* project concentrated on issues surrounding the availability of potable water while exploring local water and sewer facilities and operations. The project was implemented in 2010–2011 with substantial support from a local business partner to study water purification. In 2011–2012, the company no longer directly supported individual classes, and the course was redesigned to include field trips to a local water works and community walks to view water challenges at a more local level. The *Rollercoaster* project was added to the CincySTEM initiative during the 2011–2012 academic year. The ninth grade science teachers used it to introduce technologies that students would be using at the Hughes STEM High School and its application to project-based instruction.

Table 1
CincySTEM Timeline of Projects

Project	Class of 2013	Class of 2014
Rollercoaster	Not experienced	Fall 2011
Energy Kaizen	Spring 2010 (pilot; incomplete)	Spring 2011
Global Climate Change	Fall 2011	Fall 2012
Human Genome	Winter 2011	Winter 2012
Global Water Challenge	Intersession Spring 2011and Spring 2012 (Not all students)	Intersession Spring 2012 (Not all students)

There were highly innovative activities in all of these projects. For example, teachers in the *Energy Kaizen* project engaged students in the development of a Wikispace where they illustrated the strategies they used to calculate energy costs and consumption and also planned video tutorials on how to calculate an energy bill and implement cost-saving measures. For the *Global Climate Change* project, teachers facilitated students' preparation of a multimedia presentation in the form of an iMovie, a podcast, or a Wikispace using the F-SET backpack equipment. As part of this project, teachers also organized field trips to the Cincinnati Zoo and the Botanical Garden to provide opportunities for students to learn about different biomes and connections between the earth, plants, animals, and humans. Table 1 provides the project implementation timeline.

Teachers worked in a team organizational structure with common planning times allotted for ninth grade teachers all 3 years and common planning times allotted for tenth grade teachers only during 2010-2011. As grades were added to the school, experienced teachers were intentionally moved so that most teams included one returning teacher. The intent of this distribution of teacher experience and expertise was to induct new team members. Each team had at least one teacher who was new to the project each year. The ninth grade teaching teams had eight members over the course of the 3-year period with all teachers having at least 2 years of project experience by the end of the third year. The tenth grade teaching team had no full-time returning members in the second year. The only returning STEM Foundations teacher was deployed with the military during the second year and was replaced by a long-term substitute teacher.

As the summary in Table 2 shows, the ninth grade instructional team had four teachers working together for at least 2 years and two teachers collaborating for 3 years. These teachers were able to improve implementation of the lessons over multiple years. For the tenth grade instructional team, there was no continuity, thus new teachers were unable to make modifications based on the prior experiences of veteran teachers.

Table 2
CincySTEM ITEST Project Staffing (*Number of Years Teaching Projects*)

Planning Year	**Science** Facilitator 1	**STEM**	**Technology** Facilitator 2
Ninth Grade: Physical Science Projects			
2009–2010	Teacher 1 (1) Teacher 4 (1)	Teacher 2 (1) Teacher 5 (1)	Teacher 3 (1) Teacher 6 (1)
2010–2011	Teacher 1 (2) Teacher 7 (1)	Teacher 5 (2)	Teacher 6 (2) Teacher 8 (1)
2011–2012	Teacher 1 (3) Teacher 7 (2)	Teacher 5 (3)	Teacher 8 (2)
Tenth Grade: Biological Science Projects			
2010–2011	Teacher 9 (1) Teacher 4 (1)	Teacher 2 (1) Teacher 10 (1)	Teacher 8 (1)
2011–2012	Teacher 11 (1)	Teacher 10 (2)/Sub (1)	Teacher 12 (1)
Intersession: All Grades			
2010–2011	Teacher 1 (1) Teacher 4 (1)		
2011–2012	Teacher 1 (2)	Teacher 5 (1)	

The Evaluation Study

Data Collection

University-based external evaluators were contracted to conduct an evaluation of CincySTEM ITEST projects. Participants in the evaluation included twelve ninth and tenth grade teachers, one science and two technology facilitators, and their students (1,097 students in total). Data collected by the evaluators included the following: archival documents (e.g., lesson plans, project instructions, and students' project work), focus group interviews with teachers, Student Activity Feedback Forms (SAFF) that students filled out at the conclusion of projects; and classroom observations. The evaluation team had originally planned to use a modified Reformed Teaching Observation Protocol (RTOP) to observe at least three class periods per project. Initially piloted by The Evaluation Facilitation Group of the Arizona Collaborative for the Excellence in the Preparation of Teachers (ACEPT), the RTOP has been successfully tested for interrater reliability and construct validity. It has drawn from other sources, including NCTM Curriculum and Evaluation Standards and NRC National Science Standards, to establish its validity. Although the RTOP data collection tool would have shed light on the pedagogy used by the teachers implementing the CincySTEM projects, the instrument is cumbersome and requires observers to be in the classroom for the entire instructional time. That was not possible for these projects because they were taught over several weeks. Evaluators had to randomly select days when the projects were being taught so they could observe targeted aspects. Observations usually included one day when the teacher was delivering content, one day when the students were creating products, and another day when the students were presenting or demonstrating what they learned. To increase validity, two observers were in the same classroom whenever possible. After the observations were completed, evaluators produced a narrative summary of what they saw.

The evaluation team conducted a focus group of participating teachers each summer at the end of the academic year during regularly scheduled school professional development. These discussions occurred during the second day of summer professional development in June 2010, June 2011, and June 2012. The teachers were asked questions about classroom implementation; perceived student reactions and learning; support provided by the project team; future plans for using these projects, either in whole or in part; and any feedback for improving the CincySTEM Initiative ITEST project in the future. All qualitative data, including documents, focus-group discussions, and classroom observations, were reviewed and analyzed for emerging themes focusing on engaging students in CincySTEM ITEST projects informed by 5E Learning Cycle Principles, experience, peer support, and sustainability.

Findings

Successful projects. Observational data revealed significant pedagogical innovation in some but not all of the CincySTEM ITEST projects. In the most successful projects, students appeared to be learning science and were noticeably engaged in the assigned activities. This occurred in the *Human Genome* project in which students learned genetic science content and genealogy knowledge and used this knowledge to conduct laboratory experiments and create their own family genetic genealogies. In the *Rollercoaster* project, students created model rollercoasters using a JASON online educational module.[1] They learned about and applied scientific concepts in an iterative design process and then built rollercoasters to demonstrate applications. In the most successful rendition of the *Global Climate Change* project, the most innovative feature was the production of multimedia presentations in the form of Wikispaces, podcasts, and iMovies by students. Students were engrossed in these projects, and their engagement was heightened by the use of F-SET digital backpack equipment.

The results of Student Activity Feedback Form (SAFF) that students filled out at the conclu-

[1] Founded in 1989 by Dr. Robert D. Ballard, JASON is a nonprofit organization managed by Sea Research Foundation, Inc., which is governed by Sea Research and the National Geographic Society (http://www.jason.org).

sion of projects indicated that the digital backpack equipment enhanced learning experiences. The SAFF was administered to find out how much students were using equipment and if they felt the technologies were helping them learn science. Results on items asking whether equipment enhanced learning were generally positive with mean agreement ratings ranging between 3.40–4.38 out of 5. Written responses to SAFF open-ended questions were also encouraging. Students described how much they learned about global warming and greenhouse gases in different countries, the positive and challenging aspects of teamwork, doing research and presenting findings on PowerPoint slides, and assuming different roles in the project. With regard to the F-SET digital backpack equipment, students reported using the TI Inspire calculators, Kodak video cameras, and iPads most of the time.

These findings show the ways in which the most successful projects were pedagogically innovative, engaged students, and involved constructive use of F-SET digital backpack equipment. However, significant discrepancies between the most successful projects and other projects were also revealed in the study.

Keys to success. Some projects, simply put, were much more successful than others. One key factor in the study was teachers' accumulated experience. Teachers who were assigned to the same projects for all 3 years accumulated the experience they needed to make the projects progressively better. The *Energy Kaizen* project is a good example of this. This project was launched during the first year as a pilot, and although it was not carried through to completion, it did yield a pedagogical baseline for what did and did not work. The teacher who facilitated the pilot was assigned to that project again during the second year. She completed the project and expanded students' data collection from locations in the school to each student's home. During the third year, she managed to connect energy concepts discussed in the *Energy Kaizen* project with those in the *Rollercoaster* project. As this teacher accumulated experience, she improved and expanded the project and, as an added value, created conceptual links to other projects. She became an expert who fine-tuned the project and moved it progressively into new realms.

The crucial importance of accumulated experience was also evident in the use of F-SET backpack equipment. As teachers became more familiar with the equipment and how to incorporate it into activities, they became more adept at providing students with guidance for how to use the equipment to enhance their learning. During the second year of the *Global Climate Change* project, teachers provided students with a detailed packet of instructions to keep them engaged during their zoo trip. These instructional packets were designed to incorporate the F-SET backpack equipment provided to students. Evaluators observed students taking notes using the iPads and LiveScribe pens and paper as well as documenting their experiences with still and video cameras. Through more adept use of equipment, teachers were able to make changes to improve the curricular materials and exert a positive influence on student behavior.

Another key reason for why some projects were more successful than others was teacher peer support, especially when more experienced teachers worked directly with inexperienced colleagues (those who were new to the project). The teachers who worked together on design teams and then facilitated projects for 2 to 3 years were significantly more innovative and successful then teachers who were not on the design team or did not have years of accumulated experience. A few but not all of the teachers who were new to the project were mentored by experienced teachers. Such peer support through mentoring not only helped novice teachers overcome challenges but also ensured continuity in the development and delivery of curricular materials.

Much of the experienced teacher peer support for nonexperienced teachers occurred during common planning times that were built into the schedule. During the school's inaugural academic year (2009–2010) in which the *Energy Kaizen* project was piloted, ninth grade instructional teacher teams had 45 minutes of interdisciplinary planning time daily. During the 2010–2011 academic year, the ninth and tenth grade instructional teams had common planning time of 45 minutes daily. In 2011–2012, only ninth grade instructional teams had a common planning time of 50 minutes daily. The intersession teachers worked together for 60 minutes each week from January through April. The reduction in common planning time had a notably detrimental impact on projects facilitated by inexperienced teachers who were being left alone to figure out how to implement projects by the third year. In fall 2010, teachers who were assigned to the *Climate Change* project did not have peer support. Their curricular materials were not very detailed or clear, which caused students to become unfocused as they collected data at the Cincinnati Zoo and Botanical Garden. Students' final projects had correct factual information, but the information was not connected to the bigger picture of climate change's impact on biomes, plants, and animals. During the second year, the project was primarily led by just one teacher, which also resulted from the loss of common planning times and teacher continuity from year to year.

A third key to success was the provision of professional development (teachers were compensated for their participation by grant funds). The first professional development session occurred during summer 2010 for 3 full days during which design team teachers worked on developing projects. During the 2010–2011 academic year, teachers facilitating projects held monthly meetings to discuss implementation. The professional development sessions that took place the following summer focused on design, implementation, and forging linkages with the zoo, corporations, and other external partners involved in the projects. A 2-week whole-school professional development session was followed by teachers working in pods for 40 hours over the remainder of the summer. During the 2011–2012 academic year, the project team used a coaching model to work with grade-level teams during the year. The teams worked to better connect the projects to semester exams and state benchmarks and standards.

During the course of professional development, data from the SAFF was used to determine the extent to which F-SET equipment was being utilized. Results indicated that not all teachers involved in the CincySTEM projects were utilizing the equipment fully. There was especially low usage of the iPod Touch and iPad due to a lack of sufficient teacher expertise. A graduate assistant from a local university was hired to help teachers who needed professional development in learning to incorporate digital technology tools into their project activities. The project team also added new sections to the CincySTEM project development template to encourage teachers to purposefully plan for incorporation of digital backpack equipment and revamped summer professional development so that teachers would receive more relevant training. All of these aids helped teachers better integrate F-SET digital backpack equipment into activities.

Observations indicated that teachers who participated in professional development were significantly more innovative in their science instruction than those who did not. There was much more hands-on learning, higher student engagement, and more authentic scientific investigations of contemporary problems in the projects that they facilitated. Teachers made better use of F-SET equipment to foster skills, data collection, interpretation, and learning. Students in projects facilitated by teachers who were not involved in professional development were noticeably disengaged and disruptive, especially in classrooms in which teachers started to rely on worksheets. Professional development was a major part of the difference between teachers who were able to engage students in the CincySTEM ITEST projects and those who were not.

Challenges to success. Some teachers experienced challenges with insufficient time and crossdisciplinary content expertise. Interviews with teachers regarding challenges to sustainability of the CincySTEM ITEST project revealed that some teachers wished that they had more time to document the complexity of their work on the project website. For example, one teacher said that managing the ITEST projects for her students was her primary concern, but she did not feel she had time to provide a detailed road map for other teachers to follow her work. She describes the CincySTEM ITEST initiative as a "grand opportunity" that needed more time than they had for planning, documentation, reflection, and improvement. She said, "The amount of stuff that you need to do is exponential to the amount of time that you actually have to do it." Several other teachers in the study expressed the same concern.

The crossdisciplinary nature of the CincySTEM ITEST projects presented another significant challenge for the participating teachers. As we see in the following excerpt from the interviews, teachers said that projects required technology, language arts, mathematics, and science knowledge, which required coordination and collaboration with teachers in different content areas who may or may not have the same vested interest in the projects.

> There were actually pieces that should be facilitated in the technology class; pieces that should be facilitated in the language arts class; and pieces that should be facilitated in the math class, which means that you have to coordinate and collaborate with those teachers who may or may not have the same vested interest in the project that you do.

Collaboration was also made difficult by a lack of shared content knowledge among STEM educators, each of whom has been trained in one primary discipline. Several teachers reported that their conversations with project colleagues became most challenging when related to the content of one another's discipline of expertise.

Conclusion

We know from prior research that the design and implementation of pedagogical innovations in STEM instruction often require new teaching tools, ample professional development, and continued support. Teachers need expert knowledge and confidence in technology use to be able to engage students (Tinker & Krajcik, 2001). They benefit from regular meetings with content specialists, technology support staff, and other teachers for successful enactment of technology infused PBS (Boss & Krauss, 2007; Higgins & Spitulnik, 2008; Krajcik & Starr, 2001; Moursund, 2003; Mumtaz, 2000; Uden & Beaumont, 2006). The success of PBL projects in particular depends upon prior teaching and learning experiences with educational innovations (Ladewski et al., 1994; Marx et al., 1994), especially experiences with inquiry-based pedagogical practices (e.g., Cohen & Ball, 1990; Dreon & McDonald, 2012; Wallace & Kang, 2004). Teachers also need the support of colleagues (Tinker & Krajcik, 2001), and work on projects goes more smoothly if it is incentivized (Elmore, 1996; Towndrow, Silver, & Albright, 2010).

The findings of the evaluation study of CincySTEM ITEST projects confirm prior research, but they also contribute valuable new insights into effective ways to design and implement innovative PBL projects. Among key insights are the vital importance of teacher experience accumlated through years of carefully thoughtout implementation, experienced teachers' peer support of inexperienced teachers, and professional development in which teachers learn from each other and from outside experts. These features of the CincySTEM intiative enabled teachers to meet most of the challenges commonly associated with PBL projects and to improve projects over time. None of this would have been possible without the organization of teachers into design and implementation teams and the allocation of time for team members to work together. Teams during the first 2 years had common planning times built into their school schedules. Some of the CincySTEM ITEST projects progressed as the years progressed because the same teachers were assigned to them. These teachers accumulated experience that they could use to support colleagues who were new to the project during planning times. The team planning and organizational structure made it possible for teachers to design, implement, improve, and transmit successful CincySTEM PBL projects.

This structure deteriorated as the school grew and grant funding ended. Nevertheless, the CincySTEM ITEST projects have left a legacy. Many of the curricular materials developed during the 3-year period of the grant remain as intact projects or discrete activities. They are currently in use by eighth, ninth, and tenth grade teachers and students. Changes in Core Content Standards have led to parts of the *Global Climate Change* project being used in either the ninth- or tenth-grade science courses, and the ninth-grade biology course is using pieces of the *Human Genome* and *Global Water Challenge* projects. The *Human Genome* project activities also continue into the tenth grade science curriculum. The *Energy Kaizen* and *Rollercoaster* projects are now more aligned with the eighth grade physical science standards. Along with these core courses, 2013 intersession opportunities have utilized aspects of these projects. For example, one of the CincySTEM participating teachers had students conduct an energy audit of his house, and an architecture-focused intersession used software first identified as part of these projects and the F-SET equipment.

In addition to specific curricular materials, the project website continues to be active. It contains artifacts and is linked to the school website so that teachers have continued access. The project provided a process for Hughes STEM High School teachers to continue to check out and use the technology. Professional development has given teachers the skills and confidence to integrate technology into their instruction in a more meaningful and productive fashion. The CincySTEM ITEST projects created a curricular foundation and resources to encourage the types of projects that support students' STEM career aspirations. The challenges presented learning opportunities for the project team. Three years of work on the initiative helped solidify working relationship among teachers, school and district administrators, and university researchers and evaluators for further collaboration. That is one of the best legacies of all.

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