Action Research in STEM: Teacher-Led Projects from Primary to Middle School

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Abstract: Action research is one strategic approach teachers can use to positively influence teaching and learning in their classrooms, their schools, and beyond. Action research encourages best practice instruction, supports student learning, inspires school-university partnerships, advances the four professional development school (PDS) core purposes, and cultivates teacher leaders. This article illustrates the impact of teacher leadership on student learning in the STEM areas by reporting summaries of three teacher-led action research projects conducted in partnership with one university's Center for STEM Education. The article concludes that action research is a worthwhile endeavor for both teachers and students.

KEYWORDS: *action research, digital literacy, draw a scientist, math journals, professional development schools, STEM, teacher leadership*

NAPDS NINE ESSENTIALS ADDRESSED:

3. Ongoing and reciprocal professional development for all participants guided by need.
4. A shared commitment to innovative and reflective practice by all participants.
5. Engagement in and public sharing of the results of deliberate investigations of practice by respective participants

Ten years ago, Merrill and Daugherty (2010) observed, "Teacher leadership has become an increasingly important concept in education because it is believed teacher leaders are positioned to influence school policies and practices, student achievement, as well as the teaching profession" (p. 25). More recently, teacher leadership has been described as a "strategy for schoolwide instructional improvement" (National Institute for Excellence in Teaching [NIET], 2019, p. 3). Action research is one strategic approach teachers can use to positively influence teaching and learning in their classrooms, their schools, and beyond. By publicly conducting and sharing action research, teacher leaders demonstrate the positive impact the action research process can have on best practice instruction, which in turn can positively impact student learning (Wolkenhauer, Hill, Dana, & Stukey, 2017).

Where and in what areas should action research be conducted? The authors of this article believe that investigating teaching and learning related to science, technology, engineering, and mathematics (i.e., STEM) within the context of professional development schools (PDS) is a great place to begin. During a 2014 convocation on STEM teacher leadership hosted by the National Research Council of the National Academies, participants identified “a vast and largely untapped opportunity for STEM teacher leaders to improve student learning” (Olson & Labov, 2014, p. 13). Moreover, action research can be designed to address most – if not all – of the four core purposes of professional development schools: teacher preparation, professional development, inquiry and research, and student learning (Holmes Group, 1986, 1990). Because action research is more likely to be conducted in PDS settings than in non-PDS settings, teachers in professional development schools often experience opportunities for teacher leadership (Garin, 2017). This article illustrates the impact of teacher leadership on student learning in the STEM areas by reporting summaries of three teacher-led action research projects conducted in partnership with one university’s Center for STEM Education.

Background/Research Setting

Founded in 2011, Bradley University’s Center for STEM Education is a university-wide collaboration dedicated to increasing STEM literacy and improving STEM education and career opportunities for P-12 students (pre-school through high school), preservice and practicing teachers, and others in the Peoria, Illinois area. Co-directed by faculty with backgrounds in science education and biology, the center provides STEM-focused programs, events, and services designed to address the shortage of qualified educators in the STEM areas and support STEM-focused teacher preparation and professional development. In addition, Bradley’s Center for STEM Education contributes to the STEM knowledge base by sponsoring and disseminating research on best practices in STEM education, teaching and learning, teacher preparation, and professional development. Many of these projects are conducted as part of Bradley’s Professional Master of Arts (PMA) graduate program and focus on effective teaching practices in STEM and their impact on student learning.

Bradley’s PMA program in STEM education was designed for practicing P-12 teachers interested in becoming leaders in their field. Offered in two tracks, Elementary STEM Education (focused on primary through middle school) and Environmental Science Education (focused on middle and high school), the 33 semester hour program includes four inquiry-based content courses, five research-based courses, two teacher leadership courses, and two electives. The program culminates with a capstone project that requires teachers to design, conduct, and share the findings of classroom, grade level, or school-wide action research.

Action Research Projects

In his book, *The Action Research Guidebook: A Four-Stage Process for Educators and School Teams,* Sagor (2011) indicated that teacher-researchers must 1) clarify their vision and targets, 2) articulate a supporting theory, 3) implement an action research plan and data collection, and 4) reflect on the data collected before planning informed action to address a classroom- or school-based problem or need. During summer 2018, after conducting in-depth needs analyses and literature reviews of STEM curricula and/or current issues, all six teacher-researchers enrolled in the Elementary STEM Education master's program wrote action research proposals based on Sagor's (2011) four-stage process.

The year-long design, implementation, and reporting of the action research projects involved an ongoing partnership between Bradley's Center for STEM Education and the six-student cohort. Once Institutional Review Board (IRB) approvals and participation agreements were obtained, the six teacher-researchers implemented their action research plans during fall 2018 under the supervision of a faculty mentor. Twice during the semester, the faculty mentor met with each teacher-researcher to monitor the data collection phase, with additional e-mail contacts as needed. Upon completion of the on-site research, the teacher-researchers and faculty mentor met over a three-week period in January 2019 to analyze the data and draft scholarly manuscripts reporting their research findings. Additional mentoring was provided as needed during spring and summer 2019 as the manuscript submission and revision process continued.

Of the six teacher-researchers in the cohort, four worked independently and two worked collaboratively, resulting in a total of five action research projects. Of the five projects, two focused on case studies about students with special needs and three focused on STEM education. Following a brief review of the literature to provide a theoretical framework, this article summarizes the three STEM-focused action research projects as a basis for discussion of the important connection between action research, student learning, and teacher leadership.

Action Research, Student Learning, and Teacher Leadership

Action research enables teachers to address issues directly and immediately by trying new instructional approaches and reflecting on what does and does not work (Nolen & Putten, 2007). It is a valuable strategy teachers can use to document changes in teaching practice and student learning (Garin, 2017). However, the idea of conducting action research in addition to daily teaching responsibilities can be overwhelming for teachers (Olson & Labov, 2014). When action research is embedded within graduate-level teacher education programs, it has the potential to "develop more knowledgeable teachers, encourage improvement in student learning in schools, and contribute to the professionalization of teaching" (Vaughn & Burnaford, 2016, p. 286).

School-university partnerships that provide practicing teachers with opportunities to engage in advanced STEM-focused opportunities and experiences can "strengthen the content knowledge, pedagogy, research (especially action research), and leadership capabilities of teachers" (Merrill & Daugherty, 2010, p. 21). One year-long study of group action research projects conducted by practicing teachers and supervised by university faculty found that teacher-researchers valued opportunities to collaborate, felt more empowered to improve their teaching practice, and felt more confident participating in decision-making related to curriculum and instruction (Myers & Dillard, 2013). Action research also aligns closely with the four core purposes of professional development schools. As one example, a PDS partnership in New York that used Race-to-the-Top grant funds to sponsor 29 teacher-led action research projects found that many of the projects comprehensively supported teacher preparation, professional development, research, and inquiry, and student learning (Catelli, Carlino, & Petraglia, 2017).

When teachers conduct action research in their own classrooms and schools, they tend to become more reflective of their teaching practices (Lee, Sachs, & Wheeler, 2014), which often results in instructional improvement (Vaughn & Burnaford, 2016; Rahman, Munakata, Klein, Taylor, & Trabona, 2018). Conducting action research also has the potential to build teachers' professional dispositions and identities as quality teachers, researchers, and leaders. Vaughn and Burnaford (2016) explain, "Action research courses in which students do not simply engage in reflection, but rather are led systematically in critical reflection and critique of schools and schooling [encourage teacher-researchers] to see themselves as change agents" (p. 288).

Two recent studies conducted in professional development schools document the connection between action research, teacher leadership, and student learning in STEM education. In New York, a third-grade teacher and a university faculty member collaborated on an action research project that differentiated instruction by learning mode (e.g., auditory, visual, tactile) and incorporated peer tutoring to increase student engagement and performance in solving multi-step multiplication word problems. Results of the study revealed an 8% increase in student engagement, a 40% increase in student achievement, and documented the teacher-researchers' improvement of eight different instructional strategies (Catelli, et al., 2017). In North Carolina, a fifth-grade teacher and a university faculty member collaborated on an action research project designed to increase hands on science instruction schoolwide (Sikma & Minshew, 2018). After creating several STEM kits that included engaging, adaptable lesson plans and activities, the teacher-researcher used the kits to model innovative science instruction for teachers in the school. Although teachers did not show as much interest in the kits as the research team had hoped, the innovative science instruction systematically provided to three different fifth grade classes increased students' interest and engagement in science-related topics. Additionally, the experience enabled the teacher-researcher to expand her influence beyond the school by serving as a guest lecturer at the partnering university, presenting at a national conference, and writing a scholarly manuscript for publication.

Projects such as these illustrate what Wolkenhauer and colleagues (2017) call "a symbiotic relationship between action research and teacher leadership" (p. 122). Illustrated by the three teacher-led action research projects in the next section, action research encourages teachers to "lead *with* literature, to lead *from* data, to lead *through* sharing, and to lead *by* example" (Wolkenhauer et al., 2017, p. 127).

Three Teacher-Led Action Research Projects

Draw a Scientist: First and Sixth Grade

Background and research problem. Preconceived notions of what a scientist should look like are grounded in the Modern Expectancy-Value model, which includes "expectancy of being successful in a task and having a value for engaging in the task" (Barron & Hulleman, 2015, p. 2). The Modern Expectancy-Value model explains how one's perceptions of personal experiences build their beliefs (Eccles & Wigfield, 2002). For example, students have preconceived notions of what scientists look like and do from what they have – or have not – learned in their lives.

Concepts of expectancy and value influence many people to see only the successful end result of scientific research. However, scientists do not have all the answers. In reality, they often have to test and retest a hypothesis many times before getting a conclusive result, similar to any problem-solving effort. This is why it is important to teach students that anyone can practice the scientific method to solve any problem. Allowing students to explore scientific skills within the framework of scientists from a variety of disciplines and backgrounds provides opportunities for students to see themselves as scientists.

Draw a Scientist began in 1957, when two anthropologists performed a study asking high school students to draw a picture of a scientist. When faced with such a task, students typically draw an elderly man in a white coat surrounded by equipment in a laboratory (Chambers, 1983; Finson, Beaver, & Cramond, 2010). Even sixty years after the original study, many of the same stereotypes exist. Wondering if they were giving students the right idea of what a scientist really is and what scientists actually do, two teachers in two different Illinois school districts set out to see if exposure to new information about scientists could impact students' perceptions.

Action research process. Ninety first grade students and 119 sixth grade students participated in the study. Given simple instructions, students were given twenty minutes to draw a scientist using crayons, markers, and or colored pencils. After collecting students' drawings, both teacher-researchers tallied different aspects of the drawings, including gender, ethnicity, clothing, and hairstyles. During the next nine weeks, for 40 minutes each week, one-fifth of the participating students received specialized instruction that included research on five different scientists from different backgrounds, races, and genders, plus information about a range of scientific fields and career options. The remaining student participants did not receive the specialized instruction but instead continued with the district's science curriculum. At the end of the nine-week period, all students were again asked to draw a scientist using the same instructions and materials as before.

Research findings and discussion: The comparisons for first-grade students showed a significant change in gender between the two drawings, from 74% male scientists in the first set of drawings to 57% male scientists in the second set. The characteristics of ethnicity, clothing, and hairstyle remained fairly consistent. Sixth grade students' drawings showed a significant change in what they believed typical scientists looked like, progressing from a white man wearing a traditional lab coat to scientists that ranged in gender, clothing type, age, and race. Several students drew pictures of themselves.

Overall, the first and sixth grade students in this study showed a significant increase in depicting scientists as female, although only minor differences were noted in students' perceptions of ethnicity, clothing, and hairstyle. The results suggest that introducing students to a series of scientists could transform their view of what a scientist looks like. The data collected indicate that students' views on the appearance of scientists were impacted as a result of the specialized instruction provided, reminding teachers of the importance of expanding students' knowledge base of what scientists look like and the variety of career fields open to them.

Math Journals and Student Self-Efficacy: Fourth Grade

Background and research problem. Students with higher levels of math anxiety tend to perform lower on mathematical tasks than students with lower levels of math anxiety (Foley, Herts, Borgonovi, Guerriero, Levine, & Beilock, 2017). Math journals are one strategy for reducing math anxiety by improving students' understanding of mathematics. One study of third and fourth-grade students' use of math journals documented improved student understanding of mathematical concepts, more positive student attitudes toward math, and increased student capacity for reflection and self-assessment of learning (Scales, 2000). Similarly, Kostos and Shin (2010) found that second-grade students' usage of math journals increased students' mathematical thinking and use of mathematical vocabulary, and improved students' conceptual understandings.

Recently, the National Council of Teachers of Mathematics (NCTM) targeted goal of mathematical communication supports the integration of math and writing through activities such as math journals (NCTM, 2019).Wilcox and Monroe (2011) suggested six strategies for integrating writing and mathematics in the elementary classroom: learning logs, think-write-share, note-taking/note-making, shared writing, class books, and alphabet books. With this in mind, one Central Illinois teacher-researcher used a combination of these strategies in her fourth-grade classroom as part of a math journal action research project designed to evaluate students' understanding of math concepts and real-world applications, reveal student successes and productive struggles, and inform her teaching practice.

Action research process. At the beginning of the school year, after completing a math self-efficacy survey created by the teacher-researcher, 13 fourth grade students in the teacher-researcher's class were each given a composition notebook for math writing purposes. Throughout the school year, students were encouraged to use the notebooks as journals to detail math concepts, copy examples, create new models, list math vocabulary, and reflect upon their learning during daily math instruction. Following instruction, students were encouraged to refer to their journals to review concepts and note celebrations and frustrations related to their math learning. Occasionally, the teacher-researcher collected and responded to students' reflections as a means of supervision and encouragement. As a special accommodation, one student in the class maintained a dialogue journal with the teacher-researcher to allow for frequent back-and-forth communication and support related to math homework.

Twice during the school year, each student took home one of two shared class math journals to document real-life connections to the math concepts being practiced in class. Each journal included a checklist to guide students through the process of identifying a real-life math event using a problem-solving strategy learned in class and describing the problem and process in writing. Each class math journal entry was shared and discussed as a class. For research purposes, each shared journal entry was coded using a rubric of understanding/mastery based on the checklist criteria. Then, each entry was rated high, medium, or low. At the end of the school year, the students completed the math self-efficacy survey a second time. The coded shared journal entries and the pre/post survey comparisons were analyzed for student success in relating events in their lives to current math concepts as well as to evaluate personal growth in physical and emotional processing of math competence. Anecdotal notes from the student math journals and the student-teacher dialogue journal were used to supplement the quantitative research findings.

Research findings and discussion. Students' pre/post survey responses revealed minimal change to the questions, how do you feel about math? and, does writing about math help you understand it better? Even so, the individual and shared class math journals were successful in helping students to self-reflect on their learning and to relate mathematical concepts to real-world experiences. In her individual math journal, one student wrote, "I am good with partial products for multiplication but not as good at regrouping." Of the 26 shared class math journal entries, 50% were coded high, 46% were coded medium, and less than 1% were coded low. After working on a real-life math problem and explaining her process for solving it, another student wrote, "I did this problem because it is getting close to Christmas."

Overall, the use of math journals provided students with opportunities for reflection and revealed evidence of growth in their mathematical understanding as they made connections between math and their own lives. The math journals revealed information that the teacher-researcher would not have known had she not incorporated writing into the math curriculum.

Digital Citizenship: Eighth Grade

Background and research problem. In the United States, social media has become an integral – and often unsupervised – part of students' lives (Van den Bulck, 2004). In one study, 24 of 57 elementary-aged students said it was okay to meet with someone they knew only from the internet, and 22 students said it was okay to click on pop-ups (Ey & Cupit, 2011). Unfortunately, the more time students spend online, the more likely they are to have a negative online experience (LaRose, Rifon, & Enbody, 2008). Best practice for improving the safety of online interactions involves informing students of the dangers and teaching strategies for avoiding or dealing with these dangers (LaRose et al., 2008). To improve the safety of the online activities and choices of eighth-grade students in a rural school, one teacher-researcher collaborated with colleagues to systematically compare three digital citizenship instructional programs: Safe Online Surfing (Federal Bureau of Investigation [FBI], n.d.); Be Internet Awesome (Google, 2017); and Digital Citizenship (Common Sense Education, 2018).

Action research process. Sixty-seven eighth grade students at one middle school were placed into three groups. Each group was assigned a different digital citizenship program: Safe Online Surfing (Group A); Be Internet Awesome (Group B); Digital Citizenship (Group C). All three groups had similar student characteristics except for Group A, which included nine students with individualized education programs (IEPs).

At the beginning of the study, each student was interviewed to get baseline measurements of online etiquette and behaviors before the curricula were taught. Additionally, students were surveyed to better understand their current internet use and whether they had been an online victim or victimized someone else online within the past month. After all interviews and surveys were conducted, the digital citizenship lessons were taught each day during class time for a period of nine weeks. Each program was taught by the same teacher. Throughout each program, students kept daily logs of three to five sentences reflecting on what they learned during each lesson.

Once each program concluded, students were interviewed and surveyed again using the same questions. Students' pre- and post- responses were averaged by group and compared for changes in thinking and behavior. In addition, students' daily logs were reviewed and categorized by the teacher-researcher according to four areas of digital citizenship: manages digital identity, understands intellectual property, engages in positive attitudes online, and keeps personal data secure (International Society for Technology in Education, 2012).

Research findings and discussion. Between the beginning of the study and the end of the study, the majority of the interview and survey response means for each group improved on all questions, and the sum of the change in means for each group was positive. At the beginning of the study, students in Group A spent the largest amount of time online compared to Groups B and C. After the study, time spent online decreased for students in Groups A and C, but students in Group B showed a slight increase. Also, at the beginning of the study, several students in all groups reported being victims of online bullying or victimizing someone online. At the end of the study, the number of students participating in online bullying decreased, although witnessing online bullying and being victimized online remained about the same.

The three digital citizenship programs did not influence how much time students spent online or change the likelihood of negative student interactions online, but the need for a digital citizenship program was verified based on the amount of time students reported spending online each day. Analysis of students' daily logs revealed that all three programs taught students how to keep their personal data secure and how to engage positively online. All three programs also taught students how to manage their online identity, but Google's Be Internet Awesome stood out over the two programs in this area. Common Sense Education's Digital Citizenship was the only program that students reported learning about digital ownership of intellectual property.

Overall, the teacher-researcher concluded that, of the three digital citizenship programs, no single program conclusively emerged as most beneficial for students. Rather, all three programs rendered different benefits regarding students' understanding of how to be safer online.

Discussion and Implications for Practice

As the three teacher-led action research projects in this article illustrate, action research encourages teachers to "lead *with* literature, to lead *from* data, to lead *through* sharing, and to lead *by* example" (Wolkenhauer et al., 2017, p. 127). All three projects were grounded in scholarly literature (leading *with* literature), the conclusions drawn in all three projects were based on the data collected (leading *from* data), and all three projects were shared at state-level education conferences and reported in the form of scholarly manuscripts (leading *through* sharing). At the time of this writing, one research article has been published (Benson-O'Connor, et al., 2019) and the other two are under peer review.

In addition to leading with literature, from data, and through sharing, the teacher-researchers featured in this article continue to lead by example. One teacher leader reflected, "Pursuing this action research project made me more aware of my teaching goals and the importance of including data in my reflections." After conducting the Draw a Scientist project, this kindergarten teacher wrote and received a grant to fund a butterfly garden at her school. She stated, "Now my students can be scientists in a real project!" Along with continuing to use math journals in her fourth-grade classroom, a second teacher leader is promoting the student benefits and instructional processes of math journals by providing professional development for teachers in her region and leading social media discussions based on her recently-published article. After presenting his research findings to fellow teachers and administrators, a third teacher leader has been asked to lead the process of developing and implementing a district-wide digital citizenship program so that all students benefit. "This is still an ongoing project," he explained, "but it will strengthen our curriculum and make students feel safer."

Because these teacher-researchers are frequently called upon in their schools and school districts to supervise teacher candidates, mentor new teachers, and provide professional development, conducting action research enabled each one to accomplish the four PDS core purposes of teacher preparation, professional development, inquiry and research, and student learning (Holmes Group, 1986, 1990). In this way, action research has the potential to inspire the development of small-scale school-university partnerships, one or two teachers at a time.

Limitations

This article has two limitations. First, the background/research setting that serves as a basis for the three teacher-led action research projects is loosely defined as a school-university partnership between the teacher-researchers and a faculty member in Bradley University's Center for STEM Education. Although the setting is not a formal PDS, illustrating how universities can support teachers in conducting action research through loosely defined partnerships is intended to provide a possible starting point for non-PDS readers. Second, only summaries of the three teacher-led action research projects are reported in order to provide multiple examples of the connection between action research, student learning, and teacher leadership within one article. In addition to this composite article, each teacher-researcher individually or collaboratively wrote a full research article for publication in a peer-reviewed journal. Readers are encouraged to refer to each study's complete report as each article is published.

Conclusion

The federal Every Student Succeeds Act (ESSA) defines evidence-based professional development as "job-embedded activities that are informed by student and teacher need and designed to support strong curriculum and content" (NIET, 2019, p. 4). As the teacher-led action research projects described in this article illustrate, action research is a powerful form of evidence-based, job-embedded professional development that also encourages teacher leadership. Action research becomes teacher leadership when teachers use their research findings to inform professional development and teaching practices beyond their own classrooms (Merrill & Daugherty, 2010). When teacher leaders share action research findings with colleagues, policymakers, and the public, they positively influence student learning by contributing to ongoing development of the education profession (Lee et al., 2014). Whether the topic under investigation involves drawing a scientist, using math journals, or comparing digital citizenship programs, action research is a worthwhile endeavor for both teachers and students; it encourages best practice instruction, supports student learning, inspires school-university partnerships, advances the four PDS core purposes, and – perhaps most important - cultivates teacher leaders.

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