Effective Professional Development in STEM Education: The Perceptions of Primary/Elementary Teachers

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ABSTRACT: This qualitative study reports on the perceptions of a group of primary/elementary teachers who are engaged in a collaborative action research project, Teachers in Action, focused on enhancing STEM teaching and learning. The teacher researchers are novice action researchers from five school districts in Newfoundland and Labrador, Canada. At the beginning of the project and in the early stages of the action research process, they were asked to share their views as they relate to professional development in STEM disciplines. The research questions that guided the study are: a) What are primary/elementary teachers' conceptions of effective professional development in STEM education? b) How do these views align with current research on what constitutes effective PD? and c) How will the approach to collaborative action research adopted in this study impact primary/elementary teachers' professional learning in STEM disciplines? This chapter focuses primarily on the first two questions. Outcomes report on teachers' perceptions of the characteristics of effective professional development in science, technology, engineering, and mathematics education; the supports needed to engage in effective professional development; and the potential successes and constraints associated with professional learning in STEM education through collaborative action research.

Over the last two decades, there have been many calls for reform in teacher education (Council of Ministers of Education 1997; National Research Council 1996; Organization for Economic Co-operation and Development 2009), as well as calls for more research in teacher education (Cochran-Smith & Zeichner 2005; Darling-Hammond, Bransford, LePage, & Duffy 2005). For example, the American Association for the Advancement of Science (1998) suggests the need for change at several levels within teacher education, including changes in undergraduate teacher education, teacher recruitment, college and university teaching, and professional development for teachers. The National Research Council (1996) suggests that reform initiatives will require "a substantive change in how science is taught; and equally substantive change is needed in professional development practices" (p. 56). Others have also called for significant changes in teacher education of

both student teachers and practicing teachers. While Darling-Hammond et al. (2005) focused on teacher preparation, they noted "specifying what teachers need to know and be able to do is not a simple task" (p. 5). Moreover, they recognized the many new challenges teachers face in today's schools and the need for teacher preparation and teacher professional development that enables the learning of many different learners in diverse contexts.

These calls for improvement in teacher education reflect a perceived need to improve K–12 student learning and to ensure that classrooms have high-quality teachers.

While many factors (teacher qualifications, teacher attributes, and classroom practices) influence the development of teachers' abilities, knowledge, skills, and dispositions (Darling-Hammond & Youngs 2002; Goe 2007; Wenglinsky 2000), teachers, like those in any other profession, need opportunities to engage in ongoing, relevant professional development. Likewise, there is a strong need for primary/elementary teachers, who are the focus of this study, to engage in meaningful professional learning. Primary/elementary teachers are typically generalists and have not completed majors, or even minors in STEM disciplines. They often do not feel prepared or comfortable in teaching science and mathematics. A well-established body of research has shown that these teachers often address the challenge of teaching science and mathematics by relying too heavily on textbooks, overusing outside experts, adopting traditional approaches to teaching science and mathematics that are not student centered, and at times, ignoring science entirely so it receives very little attention in the overall school curriculum (Davis, Petish, & Smithey 2006; Holroyd & Harlen 1996; Murphy 2012; Murphy, Neil, & Beggs 2007; Trumper 2006; Zembal-Saul, Blumenfeld, & Krajcik 2000).

This study reports on the perceptions of a group of primary/elementary teachers who are engaged in a collaborative action research project, Teachers in Action, which is focused on enhancing STEM teaching and learning. The teacher researchers are novice action researchers from five school districts in Newfoundland and Labrador, Canada. At the beginning of the project and in the early stages of the action research process, they were asked to share their views as they relate to professional development in STEM disciplines. The research questions that guided the study are: a) What are primary/elementary teachers' conceptions of effective professional development in STEM education? b) How do these views align with current research on what constitutes effective PD? and c) How will the approach to collaborative action research adopted in this study impact primary/elementary teachers' professional learning in STEM disciplines? This chapter focuses primarily on the first two questions.

Theoretical Perspective

Professional development is defined in the OECD's Teaching and Learning International Survey (TALIS) as "activities that develop an individual's skills,

knowledge, expertise and other characteristics as a teacher" (Organization for Economic Co-operation and Development 2009, p. 49). While Kriewaldt (2008) states that the terms "professional development, staff development, teacher professional learning, teacher development, professional learning and teacher learning [are] broadly synonymous" (p. 3), other literature makes a distinction between professional development and teacher learning. Parr (2003) states that professional development is something "done to teachers," while professional learning is the way in which teachers "construct their knowledge and develop their skills" (pp. 69–70). Professional development focuses on the activities that teachers engage in to improve their practice, while learning implies how a teacher's practice actually changes, sometimes as a result of professional development, but also as a result of the everyday planned and unplanned activities that teachers are involved with in their classrooms (Mayer & Lloyd 2011). In a more encompassing definition, Day and Sachs (2004) merge professional development and learning, defining professional development as "all natural learning experiences and those conscious and planned activities which are intended to be of direct or indirect benefit to the individual, group or school" (p. 34). The most common trend reflected in many of the definitions is the recognition that professional development encompasses more than simple technical knowledge or learning new skills. Rather, effective professional development occurs when it allows teachers to explore the "social relations and the overlapping knowledge, theories and beliefs that direct professional action" (Fairbanks et al. 2010, p. 166).

The OECD (2009) identifies a wide variety professional development strategies, including informal dialogue among colleagues, reading professional literature, courses and workshops, conferences and seminars, qualification programs, observation visits to other schools, and individual and collaborative research, that are found to be effective. In the United Kingdom, there has been a movement toward the teacher as the "reflective practitioner" and teachers researching their own practice. This is often in response to the political focus of raising standards and making teachers accountable for their own continuing professional development (Bevins, Jordan, & Perry 2011). In the United States, the increased standards movement and desire to increase the professionalization of teaching have also led to a stronger focus on professional development that is controlled and owned by teachers (Wilson & Berne 1999). While traditional conceptions of professional development activities (e.g., workshops, bringing in outside experts) have been considered ineffective (Kriewaldt 2008; Steiner 2004; Wilson & Berne 1999), other research has shown that this is a fairly simplistic response to understanding professional development. For example, Guskey and Yoon (2009) found that in a review of 1,300 studies, only nine studies showed a positive relationship between professional development and improvements in student learning. These professional developments reported on in these studies were traditional in nature, being workshops or summer institutes, the forms of professional development that had been seen

as ineffective. Thus, it seems that the structure or professional development strategy is less important than its nature when factors such as duration and the nature of collaboration need to be considered (Steiner 2004). In contrast to the traditional professional development activities, a plethora of "reform activities" (Steiner 2004, p. 3) have emerged that offer teachers multiple ways of engaging in learning. Some of these include study groups, teacher networks, mentoring, coaching, and other collaborative formats.

Despite the professional development format, a consensus of specific criteria required for effective professional development does not exist; however, there are some common themes emerging throughout the literature (Guskey 2003). One of the reasons for this lack of uniformity results from the contextual nature of professional development; there are many variables and complexities within schools and communities that impact how a professional development program is structured and implemented. A one-size-fits-all system will probably never be found (Guskey 2003). For example, Mayer & Lloyd (2011) found, through a review of the research literature on effective professional development (Garet, Porter, Desimone, Birman, & Yoon 2001; Ingvarson, Meiers, & Beavis 2005; Kennedy 1998; Kriewaldt 2008; Meiers, Ingvarson, & Beavis 2005; Supovitz 2001; Thompson 2003; Timperley 2008; Timperley, Wilson, Barrar, & Fung 2007; Wilson & Berne 1999), that common themes could be identified. Effective professional development needs to have a focus on developing content knowledge and understanding how students learn the content (Meiers, Ingvarson, & Beavis 2005), offer teachers opportunities for active learning that is sustained over time, be structured such that teachers can try new learning in their own classrooms, allow for follow-up and teacher support when needed, and involve assessment and collective participation.

Likewise, Garet et al. (2001) adopted a six-component framework, based on a review of the literature, on what constitutes high-quality professional development. These authors surveyed teachers about their experiences and behaviors after participating in the Eisenhower program, a national funding source for teacher professional development in the United States focused primarily on mathematics and science. Based on a nationally representative sample of 1,027 teachers, features of high-quality professional development were linked to teacher outcomes (enhanced knowledge and skills and changes in classroom practices). The framework involves the following structural features and core features of professional development:

a) Structural components: Form (e.g., workshops, teacher networks, teacher inquiry); Duration (number of hours in total and the length of time over which the PD activity occurs); Participation (whether or not teachers work in groups or with colleagues and the degree of collaboration present).
b) Core components: Content focus (the degree to which the activity focuses on the development of teachers' content knowledge in mathematics and/or science); Active learning (the degree to which teachers are engaged in mean-

ingful planning, discussion, and practice through activities such as observing colleagues and reviewing student work); Coherence (the degree to which the PD is linked to previous learning experiences and school and district goals; the degree to which professional communication is fostered).

The outcomes from the study noted above reported that longer professional development activities—longer time period and more hours—had a greater positive impact on the development of teachers' knowledge and skills. Professional development activities that had a greater emphasis on content, coherence, and collective participation enhanced teacher knowledge and skills and practice. Active learning was also found to be positively correlated with enhanced knowledge and skills, but the correlation was less strong compared to the other two core features of content knowledge and coherence.

In recognition of the complexity of teaching and learning, professional development has been, and continues to be, an important part of teachers' ongoing learning and understanding. The nature of professional development and how teachers have taken up ongoing learning have shifted in the past few decades. Research needs to continue examining the impact of professional development on professional learning and practice and why and under what conditions professional learning occurs (Supovitz, Mayer, & Kahle 2000; Weiss, Banilower, & Shimkus 2004; Wenglinsky 2000). Moreover, the approaches and strategies that are adopted need to be considered carefully.

Action Research and Professional Development

Action research has been adopted in many K–12 contexts and for varying purposes to promote professional learning and teacher development (Harnett 2012; Honan, Evans, Muspratt, Paraide, Reta, & Baroutsis 2012; Razfar 2011; Sales, Traver, & Garcia 2011). In the context of STEM education, it has been used to enhance many aspects of teacher learning and classroom practice. For example, Wang, Ke, Wu, and Hsu (2012) reported on an action-research inquiry that focused on the use of blogs, Microsoft PowerPoint, and the Internet as learning tools in a project-based learning study with a grade-six class; Goodnough and Osmond (2008), using a three-part teacher knowledge and learning framework proposed by Cochran-Smith and Lytle in 1999, examined how teachers developed their professional knowledge and practice for teaching science; Di Teodoro, Donders, Kemp-Davidson, Robertson, and Schuyler (2011) reported on their experiences as four primary teachers who developed their abilities to define and ask "deeper" or meaningful mathematical questions in their teaching; Rogers, Bolick, Anderson, Gordon, Manfra, and Yow (2007) examined action research conducted by 114 experienced teachers enrolled in a Masters of Education program. The authors concluded that action research provided a vehicle for teachers to establish more personal relationships with students and to better understand students as learners.

Action research is conceptualized in different ways, often reflected in how it is implemented (Calhoun 2002; McNiff & Whitehead 2006; Noffke & Somekh 2009). To develop insight into varying approaches to action research, Rearick and Feldman (1999) developed a framework consisting of three dimensions: the theoretical orientation, the purposes of action research, and the types of reflection present. Building on the work of other authors (Carr & Kemmis 1986; Grundy 1987; Habermas 1971), they describe three theoretical orientations: technical, practical, and emancipator. The technical orientation is focused on control, with external researchers or external experts determining the research questions. This other-directed research does not foster teacher ownership and empowerment. The practical orientation to action research is focused on understanding particular contexts, such as school and classrooms events, through group reflection and collaborative meaning making. The critical orientation focuses on issues of power and societal change through empowering groups.

Rearick and Feldman (1999) categorized action research according to three broad purposes: personal growth (developing new insights into professional knowledge and practice), professional understanding (teacher development and generating new knowledge in the area of teaching and learning), and political empowerment (becoming aware of economic, social, gender, and racial inequities and directing social action to overcome these inequities). A third component, the nature of the reflection present, may involve autographical reflection, emphasizing the researcher herself and personal introspection about beliefs, perspectives, and action; public reflection in which groups of individuals pose questions that move beyond the self and a focus on understanding the actions and perspectives of others; and communal reflection that entails situating the self in relation to broader societal issues and generating public meaning through public debate and dialogue.

Despite the variations in conceptions and purposes, action research usually involves practitioners in self-contained cycles of inquiry in which they organize their learning so they can learn from their experiences and share them with others (Kemmis, McTaggart, & Retallick 2004). In this study, teachers are following a four-step cyclical process, advocated by many others (Elliot 1991; Kemmis & McTaggart 2000; Lewin 1946), that involves developing a plan of action; acting to implement the plan; observing the impact of the action in their classrooms; and ongoing reflection on this action to inform subsequent planning, reflection, and interpretation. It has a practical orientation, involves personal and professional growth, and promotes individual and collaborative reflection.

Context of the Study

The participants were comprised of twenty-two primary and elementary teachers from five school districts in Newfoundland and Labrador, Canada.

The study began with all participants coming together face to face before the start of the new school year for a one-week summer institute. During this week, the lead researcher, program specialist, and other experienced teacher action researchers introduced them to a variety of STEM-related topics and speakers, as well as provided them with the opportunity to learn about the nature of action research—conceptual and theoretical foundations, the action research cycle, how to develop plans of action, data collection and analysis, and how to share action research outcomes publicly. Of the fifteen women and seven men at the institute, six of them had less than five years of teaching experience, six of them had more than fifteen years of experience, and ten had between five and fifteen years of teaching experience.

The teachers were recruited by the program directors and program specialists in their respective districts. Drawing from the idea that collaborative action research can be challenging for individual teachers working on their own in isolation, the districts attempted to select pairs of teachers from schools in their charge. Following the institute, participants returned to their home communities to begin their new teaching year. Because of geographic challenges, a blended model of collaborative action research was deemed most appropriate to meet the needs of the teachers and the researchers in the study. During the planning and implementation process, teacher action researchers work face to face with the lead researcher, program specialists, and other participants in their geographical areas and connect with their collaborative action research community online for the remainder of the time. To allow for this ongoing communication, the researchers chose to use Desire2Learn technology to facilitate discussion and communication. This online distance platform, which is regularly used to deliver online courses, works in collaboration with Eluminate Live software to allow for synchronous and asynchronous communication.

Research Methods

The qualitative data reported in this chapter is part of a larger study that examines the experiences of all members of the action research group. This study draws upon a method of inquiry that has a long history in social sciences research. Researchers who adopt qualitative research aim to understand deeper the phenomena at hand (Creswell 2003; Denzin & Lincoln 2011). As is common in qualitative research, the study uses several data collection methods and sources. All teachers were asked to complete an open-ended questionnaire during the week-long institute, in which they responded to items such as, "Describe what you believe are the characteristics of effective professional development in science" and "In what ways can you be supported in enhancing your teaching of STEM subjects?" The researchers collected journal entries from all participants during the institute and from the online discussions with the researchers. Data were also collected during the fall term

from audiotaped collaborative planning meetings and online communications. Data collection is ongoing as teachers complete their first cycle of action research. Other forms of data collection will include interviews with the teachers, classroom observations, teacher-generated documents, and samples of primary/elementary students' work.

The data were subjected to thematic analysis. Using a data analysis software program called MAXQDA, the researchers read and reread the data holistically, recording memos as they noted patterns across the data sets. Coding followed, assigning labels to chunks of text. Next, subcategories were combined to generate broader themes such as characteristics of effective professional development, supports needed to enact effective professional development, and action research and professional learning. For the purposes of this chapter, the open-ended questionnaire and the reflective journal entries were the main sources of data analyzed.

This study was approved by the ethics review board of Memorial University. Because of the nature of collaborative action research and the role of the researchers as facilitators of action research, careful consideration was given to ethical issues that might arise during the study. To enhance the validity and credibility of the researchers' explanations and interpretations, several procedures were adopted (Maxwell 2005). Several data collection methods were used to achieve triangulation; member checking occurred with teacher participants to review researcher interpretations of the analyzed data and to try to ensure different voices were heard; and there were discussions and debriefings among the members of the action research group to examine processes and interpretations of unfolding events.

Outcomes of the Study

At the outset of the study, the teachers were asked to share their views about the nature of effective professional development in STEM and how their professional development could be supported. Furthermore, they were asked to comment on the potential benefits of the action research model adopted in this study and the challenges associated with engaging in professional development that is teacher driven, ongoing, and collaborative.

Characteristics of Effective Professional Development

Teachers were asked to complete a questionnaire during a one-week institute that focused on how to create their own action research projects in STEM teaching and learning. One of the questions asked them to identify the characteristics of effective professional development for teaching STEM subjects.

The characteristic that was identified most frequently by the teachers (90 percent) was that professional development had to be connected directly to

student learning. They described the importance of developing strategies and practical activities that would meet curricular outcomes, as well as adopting effective assessment techniques. A number of teachers focused specifically on wanting to have approaches and information that "should include . . . strategies for diverse learners in a classroom." Ensuring that all students' needs are being met was very prominent in the teachers' responses, with many teachers identifying inclusive practices as being essential.

The second most prominent theme that emerged (80 percent of teachers) was having opportunities for collaboration and sharing. This was described both as an opportunity to witness good teaching practices in other schools as well as creating opportunities for sharing ideas and having support throughout the professional development process. Finding colleagues that have experience in teaching through inquiry was suggested as a way to witness best practices. Furthermore, being able to learn about good teaching practices that are occurring in many schools was identified as an excellent way to improve their own teaching. Working collaboratively with colleagues was seen as an effective way to understand many of the ideas of inquiry in a more practical way. A number of teachers also felt that opportunities to share their own learning with others should be an integral part of effective professional development. Attending and presenting at conferences and having opportunities to share and hear what others were doing are seen as important. In addition to collaboration and sharing with each other, two participants noted that it is important to have opportunities to work with knowledgeable experts. One teacher stated: "I believe that [we should] have the 'experts' share their knowledge. They appear to have a passion and enthusiasm." Other important characteristics teachers identified included accessibility to various types of resources and support from administration. While teachers did not cite time as a salient characteristic of effective STEM professional development, they did note in another part of the questionnaire that having adequate time to engage in high-quality professional development is necessary.

Relevance of the professional development activity was seen as a key for the teachers. One teacher stated, "Professional development for teachers needs to be individualized, as we individualize our instruction for our students." Moving away from the one-size-fits-all professional development model and the importance of teachers being open to new ideas were seen as imperative. "Professional development is still often designed to teach to the whole group and thus, most people are being taught information they already know or are presented with material they are not ready to learn" (Teacher D). Being relevant and allowing for teachers to learn in new ways was mentioned many times. One teacher discerned the difference between what to teach and how to teach, stating that being offered methodologies on how to teach was more important. "Teaching methods (not cool activities) . . . but methods (e.g., think-pair-share, predict-observe, explain-observe) and techniques that allow for teachers to learn a new way to teach are needed." An important feature of

relevance, for the teachers, was focused on the content of STEM disciplines. Opportunities for "in depth study of specific concepts in science" and exploring activities that enhance teachers' knowledge of the subject area were identified as being necessary.

The opportunity to participate in hands-on activities was one of the most common statements from the teachers (95 percent). This was seen as more hands-on activities for themselves within the professional development process as well as more hands-on activities for K–6 learners. One teacher stated, "More hands-on, minds-on practical exploration and fostering of exploration in science through various media and resources are needed." Three teachers noted the need for an emphasis on technology for teaching science specifically and also for supporting their own professional learning.

Supports Needed to Enact Teachers' Vision of Effective Professional Development

Having considered what they perceive to be effective professional development, the teachers were then asked to consider the kinds of supports that they would need to teach STEM disciplines well, and what kinds of supports they would need to undertake collaborative action research. One survey question asked, "In what ways can you be supported in enhancing your teaching of STEM subjects?" Teachers also posted reflections online about the supports they believed were necessary to undertake collaborative action research in response to the question, "Based on your current understanding of action research, what do you think you need to engage in the action research process?" The analysis of the data shows that the teachers perceive time, opportunities to collaborate, provision of resources, technology access, and support and guidance from administration, program specialists, and the researcher as key features of what would be needed for success.

Without exception, teachers noted time as being fundamental: "I will need a number of release days (a minimum of five) to meet with others and discuss what I am currently working on and to ask questions that arise during the research process" (Teacher G), "Time planning for this worthwhile project is of my utmost concern" (Teacher N), "Of course, to accurately create a plan, analyze data, and prepare a report of some sort I would appreciate time that does not take away from my precious time at home" (Teacher R).

Another theme that emerged from the data showed the importance of having the opportunity for collaboration with others, ranging from fellow teachers in the project to program specialists, administration, the principal researcher, and experts in the field. This arose in over 75 percent of the responses: "A number of afternoons whereby some collaborative planning with my partner could occur would be really beneficial" (Teacher B), "I would like to convey and explain the process with our principal as well. His support would be necessary

in our continued enthusiasm and attempts with our action research" (Teacher I), "By having more opportunities to connect with the experts! I need to be shown 'how'—especially when it comes to technology" (Teacher K). Having access to resources or funds to gather resources was noted by most of the teachers, including from website subscriptions and experts in the field to iPads and books for the classroom learners.

With regard to technology, the majority of the teachers identified access to technology as their prime concern. "Technology is another area where our school at times lacks useable means of accessing technology and would certainly be an area that could be supported. Obviously, purchasing computers for all students is not viable, but access to technology is a necessity" (Teacher M). Receiving administrative support was deemed significant by over half of the teachers: "I would like to convey and explain the process with our principal as well. His support would be necessary in our continued enthusiasm and attempts with our action research" (Teacher F), "I will also need support from my school administrator and school district personnel to work through this process" (Teacher D).

Another common theme points to the role of the researcher and program specialists as providing support for the teachers as they undertake collaborative action research. This theme emerged in two-thirds of the responses. "I would also like to meet with Karen at times during the process, so that I can ask questions that arise and share what has taken place during my classroom" (Teacher S), "I can see myself wanting to meet with you once or twice, to make sure I'm on the right track and not wasting time on something that is incorrect" (Teacher T), "I may need help and support from my program specialist in math, science and/or technology" (Teacher J).

The Potential of Collaborative Action Research

After completing a one-week introduction to action research in August and moving into the beginning of the action research cycle (finding an area of focus and generating plans of action), the teachers were asked to share their views on the potential of collaborative action research for enhancing their professional learning and practice. One of the prevalent themes that emerged was a focus on student learning: catering to diverse learners; fostering learning that promotes student inquiry, critical thinking, and problem solving; and empowering students to take more control of their learning. These subthemes are reflected in comments such as:

> I will be working collaboratively with another grade-two teacher, which I thoroughly enjoy. From past experience, I know that my students will be engaged in their learning and will be actively discovering answers to their own questions and some of my questions. (Teacher S)

> The more reflective we are in our classrooms and the more innovative teaching and learning strategies we attempt in our classroom, the more benefits that the teacher and the students will experience. Students always benefit from new techniques and certainly learning that focuses on inquiry and real hands-on activities that will be a part of the action research process. (Teacher J)
>
> It is all about meeting the diverse needs of my students with exceptional needs within the school environment. I hope to use a critical lens to view my students and particular teaching strategies/supports in STEM education within inclusive collaborative practices that can increase student success. In addition, increase some aspect of STEM literacy among my students with exceptional needs. (Teacher L)

At least 75 percent of the group mentioned the integral link between improving their classroom practice and enhancing student learning. Through the action research process—adopting practices such as sharing ideas, giving each other feedback, reviewing the literature, identifying the needs of their learners, being systematic—they anticipated they would be well positioned to implement new ideas in their classrooms, examine their practice with a "critical lens," and improve many areas of their teaching. They felt this could be achieved because action research provides a guiding framework to focus on their student learning and their own planning and practice, to refine what they are doing well, and to approach their teaching in a systematic manner. About 90 percent of the teachers referred to the salient role reflection plays in the action research process: "Since reflection is a critical component of action research, I feel that it will force me to slow down and reflect on what is really happening in my classroom and in turn initiate change where change is needed" (Teacher M), "I feel action research will make me (teachers) more cognizant of what is accomplished throughout a unit, lesson or with a particular student" (Teacher A), "This project is helping me enhance, refine and reflect upon my own teaching knowledge and skills" (Teacher D), "I see myself playing a very important role as an action researcher, keeping that wheel going, piecing together bits and pieces of a puzzle in a systematic reflective manner" (Teacher C). Other themes identified by the teachers included developing more confidence in teaching STEM subjects, validating their current beliefs about teaching and learning, and having more opportunity to be part of a collaborative community.

Challenges and Action Research

Like other forms of teacher-driven or reform-based approaches to professional development (Chval, Abell, Pareja, Musikul, & Ritzka 2008; Garet et al. 2001; Lee 2004), action research can present a number of challenges that need to be considered by facilitators of action research communities and those who engage in the action research process. All teachers identified

time and organization as potential challenges in adopting the action research process. While several release days are provided to teachers to support the action research project, they still expressed concerns about the amount of time it would require outside the classroom and the need to adhere to a timeline. These concerns are evidenced in some of their journal postings:

> I think my main challenge will be to stay organized and stay on a timeline. This is something that I struggle with in my ordinary practice, so I know that I will have to stay AHEAD of things and not let tasks build up. (I am concerned that it could get overwhelming if I got behind, so I plan to set up meetings with Jane on a weekly basis to keep up to speed.) (Teacher S)

> I may find it challenging to maintain, in the long term, all that is required to be an action researcher given other commitments. We will see. (Teacher F)

> I am concerned about the amount of after-school time that will be required and expected for me to accomplish this as there are ongoing school committees, supervision, planning and preparation, not to mention my family commitments such as parenting two children and being involved in community events and programs. Time is very valuable!!! (Teacher F)

Other concerns expressed at the outset of the action research process, prior to formulating plans of action, were related to the action research process—finding an area of focus, keeping the project manageable, focusing on the needs of the students, and ensuring they chose a topic that was interesting and reflected their passion. As one teacher researcher commented, "Determining just what my passion is, concerns that my students have, and concerns that my students and I can share . . . I will need guidance and support." Finally, the teachers identified technology as a potential challenge. Some anticipated that accessing technology in their schools would be a challenge as well as having access to the Internet. Some of the teachers are in schools in remote and/or rural communities.

Discussion

The teachers shared very explicit ideas about the content (subject matter, learners and learning, and teaching methods), process (how the content should be learned), and context (factors and variables impacting particular environments) of high-quality professional development in STEM subjects (Loucks-Horsley & Matsumoto 1999; National Staff Development Council 2001). In terms of content, these authors noted that professional development in STEM should not only focus on the concepts of STEM subjects and curricular goals and objectives but should also emphasize teaching and assessment methods and practices that would facilitate learning for all students. This aligns with the literature that reports effective professional development should be directly connected to student learning, helping teachers to focus on both the "what" and "how" of student learning (Garet

et al. 2001; Hawley & Valli 1999; Mayer & Lloyd 2011; Timperley 2008). This also aligns with the notion of pedagogical content knowledge or PCK, first coined by Shulman (1986, 1987), a term that addresses the importance of integrating subject-matter knowledge and specific pedagogy in teaching. According to Shulman, PCK illustrates how the subject matter of a particular discipline is transformed for communication with learners. It includes recognition of what makes specific topics difficult to learn, as well as the conceptions students bring to the learning of those concepts. This notion has been expanded and modified by others since this time, thus indicating the importance of developing an understanding of how teachers develop their PCK and enact it in classrooms (Loughran, Gunstone, Berry, Milroy, & Mulhal 2000; Van Dijk & Kattmann 2007).

Collaboration and sharing were considered critical by the teachers for fostering professional learning. This entailed learning from colleagues through planning, exchanging ideas, offering each other feedback, observing each other during teaching, and sharing what they have learned with other educators. This also included working with other educators, such as university faculty, district personnel, and other experts who could support their learning as they engaged in the learning process. While learning is individual, many reform-based approaches to professional development recognize the importance of learning as being social (Grossman, Wineberg, & Woolworth 2001; Lieberman & Miller 2008; Wenger 1998; Wood 2007). Moreover, newer conceptions of teacher learning view teachers as being generators of knowledge and that their knowledge should be shared publicly with others (Cochran-Smith & Lytle 1999, 2009).

Relevance was deemed very important to successful STEM professional development. This entailed being relevant to the teacher and her needs, as well as the needs of her students. Part of this relevance focused on being involved in active learning, or teachers having opportunities to be engaged in "meaningful discussion, planning, and practice" (Garet et al. 2001, p. 925). This can range from observing each other as teaching occurs, accompanied by reflection and collaborative debriefing, to reviewing student work, to determining how new teaching approaches may be used in the classroom. These notions of the processes needed to enable learning through professional development align with a four-part framework published in *How People Learn*, a National Research Council document (Bransford, Brown, & Cocking 2000). The perspectives are focused on the learner, knowledge, assessment, and community. The authors argue that these four perspectives are interconnected and that each will vary depending on the alignment with the goals for learning and a particular context. In creating learning-centered environments, educators need to recognize what each learner brings to the environment and how they use these constructs within the learning environment. Factors that need to be considered include student knowledge, skills, attitudes and beliefs, and cultural contexts (Bransford et al. 2000). The

cultural contexts are also recognized in the second perspective, community centered. Classroom norms, cultural contexts, and how processes such as assessment, feedback, and relationships among students need to be considered. Connections within the school are just as important as the connections to the larger community, including "homes, community centers, after-school programs and businesses" (Bransford et al. 2000, p. 147). The third perspective recognizes that knowledge is an integral part of the environment. The knowledge and prior understanding that learners bring to an environment need to be determined to inform how to plan for instruction. Furthermore, knowledge-centered environments emphasize activities that allow learners to develop an understanding of the content of disciplines. The final perspective is assessment, both formative and summative. Continual feedback for the learner that fosters understanding and not simply memorization is crucial. The authors argue that these four perspectives are effective when they are adopted in a systems approach. They need to be coordinated carefully to ensure they are all being addressed; focusing simply on one is not likely to create a context that meets learners' needs.

In considering the context of professional development in STEM, teachers identified several elements that are needed for effective professional learning. Because the specific contexts of their schools varied, the nature of the supports required will also vary. Some teachers felt challenged by the lack of technology or a lack of access to technology in their schools. They noted that this would, to some degree, affect how they conceptualized their action research projects, as well as how they could use technology to support their own learning. While face-to-face meetings and virtual meetings are part of the support infrastructure of this project, for one teacher attending face-to-face meetings is a challenge. She lives and works in a remote community and travel to and from the community requires considerable time; thus, being away from her school three to four consecutive days (with two of these being for travel) is not feasible.

All teachers noted the importance of having other kinds of supports, such as having the support of the principal, district personnel, and university facilitators to guide them as they conceptualize and implement their action research projects; having resources available to support their projects (e.g., science or mathematics artifacts, funding to purchase access to online web tools for classes); and being able to have adequate release time to plan, share, and reflect with school-based action research colleagues and other members of the action research group. Based on the teachers' feedback, time revolved around two elements: the total number of hours available and the length of time to engage in the PD. Having adequate time has been identified as a key feature of quality professional development both generically and in STEM education (Garet et al. 2001; Timperley et al. 2007). For example, Parker (2011) recognized that effective professional development needs to be characterized by active learning, collaboration with peers, a focus on content knowledge

and classroom-based curriculum projects, time to implement what has been learned, and an emphasis on meeting both curriculum and pedagogical needs of teachers. However, how time is used is very important. The professional development activity or program needs to be well organized, structured carefully, focused on teacher needs, and linked to student learning (Guskey 2003; Guskey & Yoon 2009).

While teachers are still working through the action research cycle in this project, their early beliefs about the model of action research being adopted to foster STEM professional learning were very positive. Because the project allows them to conceptualize and focus on their own needs and the needs of their own students, and to work within a collaborative community, they felt it would be valuable in terms of fostering a better understanding of their practice and changing their classroom practice. This could be achieved by having release time and ongoing support at many levels (school, district, and university based). Action research and a plethora of "reform activities" (Steiner 2004, p. 3) are being adopted in many educational contexts to offer teachers multiple ways of engaging in professional learning. While action research has been adopted for a long time to foster teacher learning in many contexts, constraints do exist in supporting teacher professional learning through action research (Bruce, Flynn, Stagg-Peterson 2011; Jaipal & Figg 2011; James 2006; Razfar 2011).

Implications/Conclusions

The STEM movement has fueled the push for new and effective professional development throughout the United States for the past two decades and more recently here in Canada. The reports from which STEM emerged (A Nation at Risk 1983; Rising Above the Gathering Storm 2007; and Before It's Too Late 2000) have all advocated for curricular changes and a stronger focus on teacher preparation so that more teachers can effectively teach within the STEM framework (Powell-Moman & Brown-Schild 2011). Much of the thrust in professional development is to increase teachers' content knowledge in the STEM disciplines while supporting teachers in how to teach through inquiry-based instruction. For example, the National Science Teachers' Association or NSTA (Shapiro 2012) states that "professional development must show mathematics teachers how their mathematics aids scientists, technologists, and engineers in solving problems and finding solutions" (p. 1). For elementary teachers, the nature of the professional development should increase not only competence but also confidence, since many elementary teachers typically have little scientific background (Schachter 2011; Shapiro 2012).

This study has focused on primary/elementary teacher perceptions of what constitutes effective professional development in STEM education. If

teachers are to become confident and comfortable in teaching STEM disciplines, it is important to understand how to create professional development opportunities that are coherent and meaningful. Ensuring that teachers are supported by identifying needs and minimizing constraints prior to the start of a project should foster appropriate learning spaces for teachers that will assist them with possible pedagogical shifts in their understanding of STEM-related education. As discussed in the literature, professional development that does not provide relevant, contextual, and collaborative opportunities are often experienced by teachers as ineffective.

Garnering ongoing insights about teachers' perceptions of effective professional development is informing the collaborative decision-making process in the Teachers in Action project. This allows the facilitators of action research to be responsive to the contextual needs of the individual teachers throughout the province. Providing opportunities for collaboration and reflection on STEM-related professional development, as well as reflection on the process and context of the action research process, is crucial. As stated in the literature, the context is as important as the content (Guskey & Yoon 2009). While the findings of this research cannot be generalized to all primary/elementary teachers, it does provide solid argument for the need to consult with the participants at the beginning and throughout a professional development project about their ongoing needs and challenges.

On a larger scale, this study confirms some of the common themes found throughout the literature on what constitutes effective professional development and how these ideas may be used in planning and structuring professional development in STEM education. In addition to determining what is effective for individual teachers or groups of teachers, this research suggests that districts and people in leadership roles need to work collaboratively to examine what constitutes effective professional development. This can then be used to inform the development of policies and practices at school and district levels. Eliciting feedback from teachers through interviews, focus groups, or questionnaires about their professional learning needs can also provide a means to inform school and district policymaking.

As the Teachers in Action project moves forward over the next five years, the authors recognize the need to further explore how to take up the described themes and characteristics of effective professional development and embed these findings within the structure of the communities of practice that are being cultivated. Multiple opportunities for all parties to reflect on their experience and offer ideas and suggestions to inform design and implementation will be part of the ongoing process. TEP

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