Chapter 22
Designing and Evaluating an Integrated STEM Professional Development Program for Secondary and Primary School Teachers in Australia

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Contents

22.1 Introduction

In recent years, STEM (science, technology, engineering, and mathematics) education has become a focus in the Australian context, particularly since the release of government-initiated reports into Australia's declining performance on international tests and fewer enrolments in senior secondary school STEM subjects and university level STEM degrees (Freeman, Marginson, & Tytler, 2015; Office of the Chief Scientist, 2016). Studies into student engagement and motivation suggest

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students begin to disengage from the STEM subjects as early as primary school although the main shifts appear to occur in early secondary school (Martin, Anderson, Bobis, Way, & Vellar, 2012). Addressing engagement and achievement in the STEM subjects in schools requires support for teachers to design curriculum which enthuses students as well as challenges their beliefs about the role of the STEM subjects in solving real-world problems and inspires them to continue to study these subjects into the future (Moore, Johnson, Peters-Burton, & Guzey, 2016).

A year-long professional development [PD] program for secondary school STEM teachers was designed, to support teacher co-construction of integrated STEM curriculum and inquiry-based learning approaches to meet the needs of their students. Based on high-quality, high-impact PD design principles (Borko, Jacobs, & Koellner, 2010; Darling-Hammond, Hyler, Gardner, & Espinoza, 2017; Desimone, 2009), the *STEM Teacher Enrichment Academy* program involved teams of teachers from each participating school, working collaboratively to create tasks, lessons, and units of work (Voogt, Pieters, & Handelzalts, 2016) involving real-world STEM problems emphasizing creativity and critical thinking (Freeman et al., 2015). To inspire teachers to in turn, inspire their students, one of the aims of the Academy was to support teachers' knowledge and understanding of, and abilities to implement, pedagogical strategies promoting student engagement in STEM. Across a 12-month period, school-based teams of teachers participated in several face-to-face multiday sessions with university-based experts to share their work, obtain critical feedback from academic mentors and peers, and develop next steps to further their school's classroom-based STEM initiatives. Between these sessions, academic mentors visited schools to work with teams and to provide additional support. Based on the success of the Academy program for secondary schools from 2014 to 2016, a new program for primary school teachers was designed and trialed in 2017. To examine the impact of these programs, data were collected from teachers and students using both quantitative and qualitative research methods (Anderson, Holmes, Tully, & Williams, 2017).

During 2018, five STEM Academy programs were delivered—three to secondary school teachers and two to primary school teachers. While the overall evaluation approach examines changes in teachers' beliefs and practices as well as changes in students' attitudes and aspirations, this chapter focuses on data from 178 participating teachers from 61 schools. Surveys measuring teacher efficacy, teacher outcome expectancies, pedagogical practices, and STEM career awareness were administered at the beginning and end of each program.

The research questions addressed in this chapter are as follows:

1. How have teachers' efficacy beliefs (individual and collective) and outcome expectancy beliefs changed since participating in the STEM Academy program?
2. In what ways have teachers reported changing their pedagogical practices since participating in the STEM Academy program?
3. Since participating in the STEM Academy program, have teachers demonstrated any change in their understanding of future STEM career choices which may be applicable to their students?

The chapter includes a brief overview of the context of the study, a review of relevant literature in the field of integrated curriculum and quality professional learning, and the theoretical framework guiding the study based on social cognitive theory. The methodology is described with the data collection methods, analyses, and results, followed by findings, conclusions, and implications.

22.2 Literature Review

In this section of the chapter, further background information about STEM education in the Australian context is presented as well as an overview of research about the factors impacting student engagement in the STEM subjects. This is followed by research about the efficacy of integrated curriculum and key features used to design and develop the STEM Academy program based on a review of the literature on effective professional learning. Because a key feature of the program is collaborative PD, a review of research into this feature is presented followed by the theoretical framework for the study based on social cognitive theory.

22.2.1 The Context: Addressing Student Enrolment and Aspirations in STEM

Unlike other countries, it is not compulsory to study mathematics or science in the senior secondary school (grades 11 and 12) in most Australian states and territories. While enrolment patterns in mathematics and science subjects revealed small declines in the 1990s, there have been larger declines since 2000 (Kennedy, Lyons, & Quinn, 2014), and in the state of NSW, there has been a 13% decline since 2001 of students studying the more challenging calculus-based mathematics courses—necessary prerequisites for many tertiary STEM degrees (Mack & Walsh, 2014). There are also falling enrolments in some STEM-related degrees at university level with declines in the number of mathematicians and scientists in the workforce and predictions that Australia will need many more to meet workplace demands into the future (Office of the Chief Scientist, 2014). Coupled with these concerns, Australia's performance on the international assessments of TIMSS (Trends in International Mathematics and Science Study) and PISA (Program for International Student Assessment) has declined with fewer students meeting the highest benchmarks (Thomson, Wernert, O'Grady, & Rodrigues, 2016). The reasons for students' decisions to continue to study mathematics and science are complex, but these trends do need to be addressed for Australia's future economic and international competitiveness (Commonwealth of Australia, 2017).

There are many factors influencing student engagement in secondary schooling (Martin et al., 2012). By surveying teachers and careers advisors, and conducting focus group meetings with students, an investigation was conducted into the lower participation of students in senior secondary school mathematics in Australia (McPhan, Morony, Pegg, Cooksey, & Lynch, 2008). Of the four main contributing factors identified in the report, poor pedagogical practices, perceived level of difficulty, and perceived relevance of mathematics were three issues worthy of further investigation in the STEM context. Added to this, many students perceived science subjects to be difficult and uninteresting and frequently made decisions early in their schooling to discontinue the study of these subjects as soon as possible (Jenkins & Nelson, 2005). One strategy to counteract these issues suggests that mathematics and science should be taught using inquiry-based learning through real-world problems, allowing students to see the relevance of the content they are learning, particularly if the subjects are connected or integrated (Davison, Miller, & Metheny, 1995). Connecting mathematics and science curriculum with the other STEM subjects of technology and engineering has the potential to enhance student engagement and develop students' twenty-first century skills (Bybee, 2013; Vasquez, Sneider, & Comer, 2013).

Integrated learning can be implemented in classrooms in multiple ways (Davison et al., 1995) which could involve connecting content, connecting processes, or using themes to link key ideas. Further, integrating curriculum could involve a multidisciplinary approach, where teachers from two or more of the STEM subjects co-design integrated tasks, lessons, or units of work so that students have a synthesised, integrated approach to learning STEM content (Bybee, 2013). Before designing the integrated STEM PD program, further evidence was sought from the literature on the benefits of integrated curriculum.

22.2.2 The Approach: Integrated Curriculum

Integrated curriculum is not a new approach to connecting knowledge in schools. In the 1990s, Beane (1997), Vars (2000), and others (e.g., Erickson, 1998) supported the notion of middle schooling where subjects were connected to ensure curriculum content was personally meaningful for the learner. They promoted student choice of tasks with projects allowing students to fully engage in worthwhile investigations that were of substantive value to them and to society. Based on their evidence, Vars (2000) and Beane (1997) posited students in integrated curriculum environments performed as well or better than those enrolled in classes where the disciplines were taught separately. More recently, Bosse, Lee, Swinson, and Faulconer (2010) suggested integrated curriculum fosters deeper understandings, critical thinking, and motivation and forges conceptual connections—these are key components of the integrated curriculum in the *International Baccalaureate Middle Years Programme* (Daly, Brown, & McGowan, 2012), which is offered in many independent schools in NSW where this research was conducted. The STEM education movement in the 2000s (Bybee, 2013) has reinvigorated the integrated curriculum approach but with a particular focus on connecting the four subjects—science, technology, engineering, and mathematics.

However, designing an integrated curriculum for STEM education presents challenges (Nadelson & Seifert, 2017). The first is being clear about the meaning of "integrated curriculum" with many definitions evident in the literature (Choi & Pak, 2006; Honey, Pearson, & Schweingruber, 2014). The definition informing our program was proposed by Steinberg (1998):

> … we use integrated curriculum to refer to an instructional method and materials for multidisciplinary teams of teachers to organise their instruction so that students are encouraged to make meaningful connections across subject areas (p. 159)

This definition promotes the autonomy of teachers in the curriculum design process so that school teams determine how much connection between the disciplines will work in their context and acknowledges that each school which joins our program is potentially at a different starting point on their integrated STEM curriculum journey. While some researchers discuss a continuum of integration of the STEM subjects from segregated at one end to integrated at the other (Nadelson & Seifert, 2017; Vasquez, 2015), the ideal involves a "seamless amalgamation of content and concepts" so that "knowledge and process of the specific STEM disciplines are considered simultaneously without regard for the discipline, but rather in the context of a problem, project or task" (Nadelson & Seifert, 2017, p. 221).

A second challenge is managing the newly designed integrated curriculum within school structures, particularly secondary schools where students typically have different teachers for different subjects. Ideally, the school multidisciplinary team would share the same students; the planning, teaching, and evaluating; the same timetable; and even the same location within the school to enable easier communication and facilitate regular dialogue (Arhar & Irvin, 1995). Although this arrangement may not always be possible, such arrangements can help to overcome the many barriers which exist and are frequently used as excuses for the lack of success or sustainability of an innovative program. These issues were evident in the findings from studies by Venville, Wallace, Rennie, and Malone (2002) who suggest:

> In our own work, we found that examples of integration were piecemeal and idiosyncratic. They seem to rely on local champions harnessing local resources to address local issues. Few of the examples of integration we observed were sustained over time. Why is integration so difficult? We suggest that integration challenges … 'the grammar of schooling' (p. 53).

Tyack and Tobin (1994) coined the phrase "the grammar of schooling" to encompass the structures and rules of everyday instruction including organizing students into classes, allocating teachers to classes, and organizing the curriculum into separate subjects. These structures and rules are often viewed as fixed and inflexible and straight-jackets to change. For these somewhat standardized approaches to be challenged requires reforms which are supported by school leaders and adequately resourced to prevent teacher burnout (Darling-Hammond et al., 2017). There is a history of failed reforms, but integrated curriculum continues to resurface as a worthwhile strategy to reconnect students to schooling and to provide meaningful and worthwhile learning and preparation for future employment and active and informed citizenship (Bybee, 2018; Steinberg, 1998; Vickers, 1998).

To date, there is some research into the efficacy of STEM integration in secondary classrooms (Bruder & Prescott, 2013; English, 2016), and there is some evidence that STEM integration is successful in increasing student engagement within mathematics classrooms (Venville, Wallace, Rennie, & Malone, 1998), but more research is needed, and our program has the potential to provide this research as we track the impact of integrated STEM curriculum on student engagement and aspirations. To support teachers in designing integrated STEM curriculum and to help them overcome some of the barriers and impediments to change, a professional learning approach was developed. Acknowledging the differences between secondary school and primary school structures and the differences between the knowledge of STEM disciplines between secondary school teachers and primary school teachers, the STEM Academy program adopted different structures for each of the secondary school and primary school programs to address differences in participants' needs. The design of the secondary and primary school programs is outlined in the next section with descriptions of these differences.

22.2.3 The Program: Designing the Professional Development

The program design and development was informed by the features of effective PD as described by Darling-Hammond et al. (2017). By reviewing "35 methodologically rigorous studies that have demonstrated a positive link between teacher professional development, teaching practices and student outcomes" (p. v), the researchers identified seven features of effective PD—it is content focused, incorporates active learning, supports collaboration, uses models of effective practice, provides coaching and expert support, offers feedback and reflection, and is of sustained duration. The overall program delivery model and a brief description of the sessions within the primary and the secondary programs is presented in the next section to demonstrate the inclusion of each of these features.

The Secondary School Program

The secondary school PD program began with a 3-day face-to-face immersive experience where each of 12 participating schools sent a team of six teachers (typically two each of mathematics, science, and technology/engineering). After working intensively with the academic mentors, each school team designed an integrated STEM curriculum program to be trialed with their students before the next face-to-face 2-day meeting later in the school year. On returning to school after the 3-day PD, teachers refined programs and began to trial tasks, lessons, and projects with a targeted group of their students and classes—typically grades 7 or 8 where the curriculum is more flexible and teachers feel they have less pressure from high-stake external examinations. Throughout the course of the year, academic mentors visited schools to provide additional support, discuss issues, and make suggestions for overcoming challenges in program implementation.

The Primary School Program

The primary school PD program usually involved 14 schools sending teams of two to four teachers depending on school size. Face-to-face, multiday meetings were held at the beginning, middle, and end of the school year, and teachers were similarly supported by academic mentors. Since all teachers had a breadth of knowledge of school curriculum requirements across each of the STEM subjects, sessions tended to focus on developing deeper content knowledge and connecting the subjects in more authentic ways. Most teacher participants were teaching grades 3 or 4 or held leadership positions in their school. While many of these teachers were familiar with integrated curriculum, they were less familiar with integrated STEM curriculum and frequently unaware that their attitudes toward mathematics and science and their knowledge about STEM careers had the potential to influence their students' attitudes and aspirations (Nadelson et al., 2013).

The Features of Effective Professional Development

This section notes how the seven features of effective PD were addressed in our programs. Both Academy programs were *content focused* with opportunities for teachers to develop knowledge and understanding in each of the STEM subjects, regardless of their subject expertise, as well as across the STEM subjects where the content was integrated and connected in a range of learning experiences. With support from academic mentors, teachers *actively* developed knowledge of inquiry learning by engaging in *collaborative* small group activities in each of the STEM disciplines as well as in integrated project-based activities. For example, the secondary school teachers in their school teams investigated issues of sustainability by designing experiments to collect data on energy consumption, investigating power-saving devices including those using solar power, and developing questions to model inquiry activities suitable for their students. The primary school teachers designed wind powered cars, exploring the features required for maximum speed and stability, examining the forces on the vehicle, and collecting and analyzing data to support their findings.

Throughout each of the programs, *experts modeled effective practice* and provided *feedback* as teachers shared their experiences. During each program, teachers worked in school teams but were encouraged to discuss their experiences with teachers from other schools and to share resources, ideas, activities, and lessons using the Edmodo online platform. As each program was delivered over a 12-month period, the feature of *sustained duration* was also evident in the design of the PD.

Additional features have been identified as critical to the success of effective PD including support from school leadership, aligning school plans with the outcomes of the program, a supportive school culture, providing sufficient resources, and responsiveness of program designers to the needs of teachers and their students (Darling-Hammond et al., 2017; Rawolle, Wells, Paatsch, Tytler, & Campbell, 2016). To ensure a commitment from the school principal, each participating school was required to submit an "expression of interest" prior to selection which clearly identified what the school was currently doing in STEM education, what problem they wanted to address during the 12-month period of the program, and how their STEM proposal was aligned to the school strategic plan, which teachers would be involved, what support they would receive, and how changes could be supported and sustained after the 12 months PD. On completion, schools were required to submit a final report, providing supporting evidence of achievement of each of these outcomes.

Based on the notion that implementing an integrated STEM education initiative in the school was part of the school's improvement plan, Rawolle et al. (2016) highlighted the importance of many of these features based on their case studies of effective school improvement.

> Professional learning opportunities, a whole school focus around evidence-based teaching, the development of a culture of sharing of ideas and experience with peers and curriculum coaches demonstrated the value of 'ecologies of practice'. In these schools, the collaborative nature of the school improvement process right across the school lead to sharing of problems and successes and a positive culture in relation to school improvement with teachers acting as willing participants in change processes supported by leaders who were willing to join in the learning journey (p. 133).

Given the importance of collaborative professional development in creating a culture of change for new initiatives, the following section discusses the evidence from relevant research.

22.2.4 A Key Feature: Collaborative Professional Development

Engagement in PD experiences has shown to positively influence teachers' self-efficacy beliefs (Ross & Bruce, 2007). Reporting on a 2-year project centering upon teacher efficacy beliefs, Durksen, Klassen, and Daniels (2017) posit that the most influential aspect of professional learning on efficacy beliefs is "collaboration with other teachers" (p. 59). Additionally, they found that for mid-career teachers, PD experiences that afforded teachers "the time and space to think" (p. 61) with other colleagues were also a significant predictor of efficacy beliefs. Not only do teachers benefit from participating in professional learning experiences with other colleagues, but "teachers can only really learn once they get outside their own classrooms and connect with other teachers" (Hargreaves, 2009, p. 98). Collective participation, as noted by Desimone (2009), is a key feature of effective PD. The type of discourse and collaboration that occurs when teachers from the same school engage in professional learning of sufficient duration can be a highly influential form of teacher learning since teachers may have already established a certain level of rapport adding to the effectiveness of collaborative PD (Penlington, 2008).

In their systematic review of studies on collaborative PD, Cordingley, Bell, Thomason, and Firth (2005) found that collaboration among teachers who participated in curriculum design project teams was not only beneficial for the professional learning gains of the teachers involved but also paramount to the intended programs' successes. Additionally, they summarized other key benefits of teachers who participated in collaborative PD which included increased confidence and commitment to investigate and implement changes in practice, increased beliefs of teachers in their ability to affect student learning, and the growing enthusiasm for teachers to work collaboratively. Nadelson et al. (2013) report on a three-day summer institute focused on improving primary school teachers' ability to teach STEM from an inquiry-based perspective and the resulting impact of this program on teacher efficacy beliefs. Their analysis revealed that the increased level in teacher self-efficacy as measured in a pretest/posttest program design was still present two years after teachers completed the institute.

High-impact professional learning experiences are often those with more than 20 hours of contact time (Desimone, 2009). Knowles (2017) reports on the professional gains of teachers who participated in the TRAILS (*Teachers and Researchers Advancing Integrated Lessons in STEM)* program, a 2-week summer professional development program for science and technology teachers. To assess changes in teacher self-efficacy, Knowles administered the T-STEM instrument (Friday Institute for Educational Innovation, 2012) to the teacher participants and to a control group of teachers in a pretest/posttest/delayed posttest design. While the control group showed no change in perceptions of self-efficacy, the experimental group of teachers showed a significant change in self-efficacy from pretest to posttest, with posttest levels sustained in the delayed posttest measure.

22.2.5 The Theoretical Framework: Social Cognitive Theory

Grounded in social cognitive theory (Bandura, 1997), teacher self-efficacy is often identified as one of the most important affective outcomes of teacher professional growth. As such, it becomes an important area for examination and thus forms the theoretical tenet for this study (Klassen, Tze, Betts, & Gordon, 2011; Tschannen-Moran & Hoy, 2001). At an individual level, self-efficacy can be thought of as self-belief in one's abilities to plan and implement actions that will in turn produce an intended outcome (Bandura, 1997). In an educational setting, a teacher's self-efficacy may be referred to as their personal perception of their skill level or competency to teach their subject matter or facilitate the educational task at hand. Nadelson et al. (2013) suggest that "efficacy may be a proxy for the larger issues of teacher knowledge and preparedness of teaching STEM content" (p. 159) and may be a central influencing construct that has the power to positively affect teacher success in the classroom. Within a STEM educational learning space, inquiry-based instructional practices that aid student learning in STEM have also been positively correlated to teacher self-efficacy beliefs (Lakshmanan, Heath, Perlmutter, & Elder, 2011). Additionally, teacher self-efficacy beliefs have been linked to other positive practices such as student-centered classrooms (Enochs, Scharmann, & Riggs, 1995) as well as proving influential toward promoting student success (Settlage, Southerland, Smith, & Ceglie, 2009).

Social cognitive theory also suggests an additional kind of self-belief distinct from efficacy beliefs in that of outcome expectancy. While a teacher's self-efficacy may reflect their personal belief in their capacity to successfully teach within their subject domain, outcome expectancy is a teacher's estimate of their ability to influence student learning through their teaching (Bandura, 1986). Tschannen-Moran and Hoy (2001) further define outcome expectations as a teacher's "judgment of his or her capabilities to bring about desired outcomes of student engagement and learning, even among those students who may be difficult or unmotivated" (p. 783). While self-efficacy and outcome expectations are independent measures of teacher perceptions, they are both important attributes affecting teacher behavior as they each stem from an individual's self-projected level of competency (Bandura, 1986) and have the potential to be positively shaped through PD (Nadelson et al., 2013).

A more recent construct in efficacy research centers upon the concept of collective efficacy. Bandura (1997) defines collective efficacy as "a group's shared belief in its conjoint capabilities to organise and execute the courses of action required to produce given levels of attainment" (p. 477). In schools, collective teacher efficacy can be understood as the perceptions that a group of teachers hold in their ability to jointly influence the academic outcomes of their students (Tschannen-Moran & Barr, 2004). Schools or teaching programs that demonstrate excellence often reflect their teachers' sense of collective efficacy (Durksen et al., 2017). Teachers not only hold individual beliefs regarding their personal perceptions of efficacy, but they also possess beliefs about the capability of the group of teachers with whom they work in a school setting (Goddard, Hoy, & Hoy, 2000). Collective teacher efficacy is not simply a sum of the perceived efficacy levels of the individual teachers within a community of teachers but instead is the teachers' perceptions of how well a defined cluster of teachers with whom they work can affect positive educational outcomes in their students (Bandura, 2000). Prior studies have indicated a strong relationship between collective efficacy and student achievement when measured between schools (Goddard, 2001).

Within the context of the *STEM Teacher Enrichment Academy*, teams of teachers from the same school worked collaboratively to design and deliver integrated STEM curriculum. Assessing measures of perceived collective efficacy may offer an opportunity to understand the dynamics at play within schools that foster STEM teaching and learning goals which in turn may positively impact student achievement. To explore the self-efficacy and collective efficacy of the teachers involved in our program, surveys were administered before and after delivery of the program. The next section of the chapter outlines the methodology including the participants, the instruments, and the data analysis.

22.3 Methodology

22.3.1 Participants

All teachers who participated in the 2018 STEM Academy programs were invited to participate in this research. This included mathematics, science, and technology teachers from three secondary school programs and generalist teachers from two primary school programs. Teachers represented schools from the Government, Independent, and Catholic sectors in NSW Australia. Those teachers who consented to participate completed a pre-survey at the start of the first face-to-face meeting. Later in the year, at the completion of the last face-to-face meeting, teachers completed a post-survey. While the surveys were anonymous, a code was created so teachers' pre- and post-surveys could be matched for analysis. A total of 178 teacher surveys (108 secondary, 70 primary) were matched (see Table 22.1) and used for analysis. Most primary and secondary teacher participants had more than 10 years of teaching experience (see Table 22.2).

22.3.2 Instrumentation and Data Analysis

The teacher survey used in this study consists of items taken directly from the *T-STEM* survey instrument (Friday Institute for Educational Innovation, 2012) and the *Collective Teacher Efficacy Measure* (Goddard et al., 2000). The designs of both these published instruments are firmly grounded in social cognitive theory (Bandura, 1986, 1997; Tschannen-Moran, Woolfolk Hoy, & Hoy, 1998). While the *T-STEM* survey (Friday Institute for Educational Innovation, 2012) contains six constructs, only four were applied in this study—those which assessed teachers' personal STEM teaching efficacy beliefs (PTEBS), STEM teaching outcome expectancy beliefs (TOES), STEM instructional practices, and STEM career awareness. Of the two constructs contained in the *Collective Teacher Efficacy Measure* (Goddard et al., 2000), only the *Assessment of Teaching Competence* construct was used in this study as it considers the teachers' perceptions of their team's teaching skills and expertise and seemed an appropriate measure of assessing the potential effect of collaborative PD with a team of teachers from the same school. Although the *Collective Teacher Efficacy Measure* is not STEM specific, language was adapted to reflect an appropriate STEM context (see Table 22.3).

Table 22.1 Secondary and primary teacher pre- and post-survey participants

Program	Completed pre-surveys	Completed post-surveys	Matched surveys	% matched
Secondary	175	139	108	62%
Primary	102	85	70	69%

Table 22.2 Descriptive breakdown of teacher type and years of teaching experience ($n = 178$)

Years teaching	Primary teachers	Secondary maths	Secondary science	Secondary technology	Other secondary	Total
Not reported	1	0	0	0	0	1
< 3 yrs	2	2	5	5	6	14
3–5 yrs	12	3	5	2	0	22
5–7 yrs	8	0	3	3	1	15
7–10 yrs	11	5	6	4	0	26
>10 yrs	36	22	21	17	4	100
Total	70	32	40	31	5	178

Table 22.3 STEM Academy teacher survey design with adapted use of the T-STEM survey and the Collective Teacher Efficacy Measure

Instrument	Construct	Measurement	No. of items	Sample item	Likert scale
T-STEM survey	Personal teaching efficacy beliefs in STEM (PTEMS)[a]	Confidence and self-efficacy in the context of teaching STEM within a defined subject area	11	I am confident I can answer students' STEM related questions within my main teaching area.	1 = SD to 5 = SA
T-STEM survey	Teaching outcome expectancy beliefs in STEM (TOES)	Perception of influence in regards to students' learning	9	The inadequacy of a student's background knowledge can be overcome by good teaching	1 = SD to 5 = SA
T-STEM survey	STEM career awareness	Knowledge of current STEM careers and how to locate relevant resources on STEM careers	4	I know where to find resources for teaching students about STEM careers	1 = SD to 5 = SA
T-STEM survey	STEM instructional practices	How often students engage in the described tasks during class time	14	Develop problem-solving skills through investigation or inquiry	1 = Never to 5 = Every time
Collective Teacher Efficacy Measure	Group competence	Assessment of teaching competence of team of teachers from the same school	13 (6 negatively worded)	Teachers on our STEM team have what it takes to get students to learn	1 = SD to 5 = SA

[a]The PTEBS construct was not included in the primary teacher survey since they were not subject specialists

In the construction of the T-STEM survey (Friday Institute for Educational Innovation, 2012), the items related to the PTEBS and the TOES were revised from the Science Teaching Efficacy Beliefs Instrument (STEBI; Riggs & Enochs, 1990) to reflect language more applicable to modern teaching. The STEM Career Awareness construct was newly created for the *T-STEM* survey, and the STEM Instructional Practice construct was adapted from the North Carolina's Race to the Top PD evaluation (Corn et al., 2013). In its initial design, the different constructs of the *T-STEM* survey underwent factor analysis with principal axis factoring and promax rotation. Loadings above 0.3 were considered significant. The reliability analysis for the different factors produced excellent results with Chronbach's alphas ranging from 0.84 to 0.95.

In this study, the primary and secondary teachers' pre-surveys and post-surveys were aligned in content except the primary teacher survey did not include the PTEBS because of its focus on subject specialization. Additionally, the post-surveys contained four open-ended reflective prompts that asked teachers to share personal growth highlights because of their participation in the STEM Academy program or perceived needs for future PD in STEM teaching.

Pre- and post-surveys were matched based on a predetermined coding scheme. Matched pair analysis was undertaken using Wilcoxen-signed rank tests, with effect sizes for each construct also determined ($Z/\sqrt{n}$). Reliability analysis was undertaken by determining a Chronbach's alpha for both pre- and post-test factors. The teacher responses from the post-survey open-ended prompts were uploaded into nVivo v.10 for analysis. Key themes were determined using thematic and content analysis (Miles & Huberman, 1994). The following section of the paper outlines the results of the study.

22.4 Results

The pre- and post-survey comparisons revealed changes in teacher efficacy, in STEM career knowledge, and in teachers' pedagogy. Each of these changes is presented in the next section of the chapter followed by further evidence of change from teachers' reflective comments included in post-surveys. Teachers' reflections are presented in response to open-ended questions about each of changed perceptions of STEM teaching and learning, changes in pedagogy, perceptions of the need for future support, and personal hopes for future growth in STEM teaching.

Table 22.4 Comparisons of pre- and post-scale indicators using Wilcoxon-Signed Rank Tests ($n = 178$)

Scale	Pre-test mean	Post-test mean	Z	P	r (effect size)
Teacher self-efficacy[a] Secondary (pre $\alpha = 0.902$; post $\alpha = 0.868$)	42.10	47.89	−7.75	0.000***	0.53
Teacher outcome expectancy Secondary (pre $\alpha = 0.752$; post $\alpha = 0.752$) Primary (pre $\alpha = 0.749$; post $\alpha = 0.814$)	29.86 31.78	31.06 31.88	−3.21 −0.06	0.001** 0.856	0.22 –
Collective efficacy group competence[c] Secondary (pre $\alpha = 0.807$; post $\alpha = 0.848$) Primary (pre $\alpha = 0.881$; post $\alpha = 0.877$)	54.86 56.67	55.68 57.56	−1.54 −1.10	0.124 0.271	0.10 0.14
STEM career knowledge Secondary (pre $\alpha = 0.918$; post $\alpha = 0.887$) Primary (pre $\alpha = 0.886$; post $\alpha = 0.851$)	12.66 11.59	15.87 15.52	−7.15 −6.63	0.000*** 0.000***	0.49 0.56

Notes: Scale ranges: a. 11–55; b. 9–45; c. 13–65; d.4–20: Effect size small = 0.1; medium = 0.3; large = 0.5

*** $p<0.001$, ** $p<0.01$, *$p<0.05$

22.4.1 Pre- and Post-Survey Comparisons

Changes in Teacher Efficacy

The comparison of pre- and post-test survey responses yielded statistically significant results across a range of factors (see Table 22.4). Secondary teacher gains in *individual self-efficacy* were highly significant with a large effect size ($Z = -7.75$, $p = 0.000$, $r = 0.53$). Additionally, secondary teachers' increase in measures of *outcome expectancy* was also statistically significant ($z = -3.21$, $p = 0.001$, $r = 0.22$). While the comparison of primary teachers' pre- and post-survey responses for *outcome expectancy* did not yield statistically significant results, their mean responses on the pre- and post-surveys both exceeded the post-survey mean for secondary teachers, perhaps indicating a ceiling effect in this measure for the primary teachers. Neither secondary nor primary teachers displayed statistically significant changes in their measures of *collective efficacy*. The pretest means for both primary and secondary teachers indicated strong levels of perceived group competence even before the teachers engaged with the STEM Academy program. This measure of perceived competence of the teachers on their school's STEM team may be impacted by the accumulated professional experience of their team's teachers, since most teachers in this study have more than 10 years of teaching experience.

However, when the teachers' measures for *collective efficacy* are delineated based on years of teaching experience, statistically significant results do emerge. Secondary teachers with less than 3 years of experience displayed a statistically significant difference in their measure of *collective efficacy* ($z = -1.961$, $p = 0.05$) from pre-survey to post-survey. Primary teachers with less than 5 years of experience also indicated a marginally significant positive change in their measure of *collective efficacy* ($z = -1.891$, $p = 0.059$). For the teacher participants in this study, those with less teaching experience indicated greater gains in their perception of the *collective efficacy* of their STEM team than those with longer teaching experience.

Changes in STEM Career Knowledge

One of the aims of the STEM Academy program was to increase teacher's knowledge and understanding of STEM careers. Both secondary and primary teachers displayed highly significant changes in their STEM career knowledge since their involvement with the STEM Academy (see Table 22.4). This includes knowledge about current STEM careers, where to go to learn about STEM careers, where to find resources for teaching students about STEM careers, and where to direct students or parents to find information about STEM careers.

Changes in Pedagogy

The STEM Academy program encourages teachers to foster a classroom environment that adopts a more inquiry, student-centered approach. As part of the survey, teachers were asked to indicate how often students engaged in prescribed tasks or learning strategies during their teaching time and comparisons were made between pre- and post-survey responses (Table 22.5).

Teachers' responses indicate positive reported changes in their pedagogical approaches aimed at enhancing student-centered learning in STEM. Since attending the STEM Academy, and implementing student-centered STEM tasks, lessons, and projects, many teachers reported changes in their pedagogical practices that were also statistically significant. The quantitative data analyses revealed significant changes in several aspects of teachers' efficacy beliefs and pedagogical practices. The following section affirms these changes through teachers' reflective post-survey comments.

Table 22.5 Student engagement in prescribed tasks during class time: comparisons of primary and secondary teacher indicators pre- and post-academy using Wilcoxon-Signed Rank Tests

During class time, how often do students …	% Secondary teachers that indicate increased time on specified task from pre- to post-Academy	% Primary teachers that indicate increased time on specified task from pre- to post-Academy
Develop problem-solving skills through investigation or inquiry	44%***	46%***
Work in small groups	35%**	29%
Make predictions that can be tested	29%	39%
Make careful observations or measurements	25%	38%
Use tools to gather data, e.g., calculators, computers, software, scales, rulers, …	29%	40%
Recognize patterns in data	25%	37%*
Choose the most appropriate methods to express results (e.g., drawings, models, charts, graphs, technical language)	34%	40%**
Create reasonable explanations of results of an experiment, investigation or inquiry	37%	50%**
Engage in content driven dialogue	40%*	43%**
Reason abstractly	44%**	48%**
Reason quantitatively	31%*	43%**
Complete activities within a real-world context	22%	51%**
Critique the reasoning of others	40%	57%***
Learn about careers related to the STEM subject content	28%	57%***

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$

22.4.2 *Teacher Reflections*

After the STEM Academy, teachers were asked to reflect on their experiences and the perceived impact and influence of this PD program. In particular, they were asked to offer their thoughts on their changed perceptions of STEM teaching and learning, the changes in their own approaches to teaching, their perceptions of future support needed to continue along a STEM teaching pathway, and perceived areas for future growth in their STEM teaching. Responses were uploaded into nVivo v.10 and coded for emergent themes. This section explores and describes the prominent themes as offered by the collective voice of the teacher participants.

Changed Perceptions of STEM Teaching and Learning

Although teachers offered a plethora of comments on how their perceptions of STEM teaching and learning shifted through their participation with the STEM Academy, four key themes consistently emerged across the teacher reflections—an awareness and ability to connect teaching content in curriculum across the STEM subjects, the vital importance of collaboration, increased student engagement, and the importance of engaging students in real-world problem-solving.

Inherent in the acronym of STEM are the key learning areas of science, technology, engineering, and mathematics. For many teachers, their journeys with the STEM Academy afforded them the novel experience of moving away from siloed subject teaching within their STEM domain, to shifting toward developing a more inclusive curriculum that purposely linked the discipline content between the STEM subjects. This was a dominant key concept expressed by many of the teachers—a sample of reflections is offered below.

"I have changed my thoughts about how STEM should be implemented. I think it is great to have faculties shaping programs around a theme to help students make connections between subjects and real-world connection with their learning."

"I have a greater understanding of STEM and its importance for future careers. I now see and appreciate the importance and connection of the subjects."

"I have a better understanding of how STEM can be integrated into the curriculum rather than something extra."

"My teaching has changed as I feel a real need to work more closely with science and technology instead of separately."

While collaborating across subjects was a new experience for many secondary teachers, they quickly learned that forming effective working relationships with teachers on their team was critical to their program's success. If STEM content was to be effectively delivered across subjects, then strong interfaculty relations needed to develop. For many teachers, a highlight of their STEM Academy experience was the opportunity to collaborate with other teachers with an added benefit of team teaching. As expressed by one of the teachers, "so excited we can work as a team." Another teacher reflects, "I have learned that collaboration between teachers is essential to the success of any of these programs." Collaboration offered a common platform from which teachers could share knowledge while working toward the same goal.

Teachers also found that collaboration centered upon delivering inquiry-based learning opportunities increased student engagement, which in turn fuelled teacher enthusiasm. While several teachers commented on positive changes in student engagement, the following teacher's comment offers a fitting summary expressed by several of the teachers, "I have become more excited about the (STEM) program since teaching it. I can now see first-hand the engagement and excitement students have for a different style of learning," with another teacher adding that "excited by student interaction with STEM classes, has developed my own excitement towards teaching STEM."

Changes in Pedagogy

Many teachers reported, through participating in the STEM Academy, they had adapted and implemented more inquiry-based and project-based learning strategies within their classroom practice. This included, as one teacher notes, "consciously implementing STEM projects/activities in my everyday teaching." Another teacher describes, "I have given students more space to investigate and learn through inquiry." Many teachers shared how this less didactic approach to teaching has also facilitated teaching and learning styles that are more student-centered and less teacher-centric. As one teacher explains, "I am now providing students with more feedback in the process of projects. Instead of feeding them the answer, being a facilitator, rather than a lecturer."

For some teachers, the process of letting go of tight control in the classroom was a newly acquired pedagogical skill. Many teachers commented on the process of this shift toward more student-centered learning. As one teacher reflects, "I have learned to let go and allow students to feel that awkward, stuck moments to find their own way out of it, without prompts from me." Another teacher shares that she is "getting students to question more, think outside the box and see that they can actually achieve things that they thought they couldn't." Overall, a common theme shared among teachers was their growth in letting students discover, investigate, experiment, and drive their own learning.

These reported pedagogical shifts in teacher practices are also paralleled by teachers' growth in their knowledge, confidence, and motivation in delivering STEM learning. Many teachers shared their emergent confidence gained over the course of the year with the Academy as highlighted in the following comments.

"I have a positive outlook and enthusiasm to teach STEM. I have gained confidence in STEM delivery and developed a better understanding of how subjects linked with this initiative."

"I am more confident to teach STEM. Seeing how others teach, the opportunities available and resources available means we have built up our own skills/knowledge. This makes my teaching have greater breadth/capacity."

"I thought that I didn't have the skills to teach STEM. I know now that I can learn along the way as I teach STEM."

It appears that a key benefit of the STEM Academy in the lives of teachers was growth in their self-efficacy. As one teacher simply states, "I know I can do it now."

Perceptions of Future Needed Support

For teachers and schools that are continuing along a STEM pathway, having more time to design and implement STEM pedagogies with colleagues was the most salient future need to keep their STEM program moving forward. Designing new curriculum takes concerted effort and time, and for many teachers, this planning time was often in addition to their full-time teaching load. As one of the participants reflects, “I feel the road to developing STEM is ongoing … it is time to continue development of activities, resources and teaching ethos.”

Another felt need of participants was their desire to have ongoing connection with mentors and colleagues from the Academy. One of the hallmarks of the Academy is the mentoring that is provided to each school’s STEM team throughout the year. Additionally, each Academy’s cohort of approximately 60 teachers become peer mentors to one another through the sharing of ideas and resources between and among their schools. Many teachers highlighted their desire for ongoing support through both peer and academic mentoring. As expressed by one of the participants, “I would love ongoing communication with our mentor, as well as being able to see what other schools are doing in STEM.” Another teacher reflects that they would appreciate, “more increased sharing or resources related to STEM education, project-based learning, ideas and resources for specific projects.” Teachers also expressed a strong desire for continued PD to increase their skills in STEM, particularly in coding, or computer programming.

Teachers’ Personal Hopes for Future Growth in STEM Teaching

As teachers reflected on the areas that they perceived as important for their future growth as STEM teachers, they most often shared that they would welcome more opportunities for collaboration for teaching across the subject boundaries, would desire to implement more student-directed learning within their classrooms, and would hope to upskill in STEM disciplines outside their area of expertise. Not only was collaboration across STEM subjects one of the most noted changes in teachers’ approach to pedagogy, but it was also the greatest expressed hope for future growth in teaching as expressed by the teachers in this study. As one teacher comments, “I would love the opportunity to team teach with staff in other [subjects] … to show our students that we are also STEM teachers and can move across areas.” And another shares, “… more collaboration of various [subjects] in school and be able to demonstrate that link to students to make their learning worthwhile.”

Teachers noted that student-directed learning that focused on real-world problem-solving often led to increased student engagement in their classrooms. As such, teachers hoped that in the future they would be able to incorporate more opportunities in which their role was more of a facilitator and less a director of student learning. Teachers hoped “to become better at encouraging students to test and experiment with design solutions and encourage students to go for a broad variety of possible design solutions.” Teachers also hoped to design “better projects that make students want to learn—students becoming accountable for their learning.” Finally, teachers wanted to also further develop in their pedagogical content knowledge across the STEM disciplines, particularly as it relates to gaining greater digital technology usage and deeper understanding of engineering principles which often anchors the integration of the independent STEM disciplines.

While teachers’ reflections reported positive changes in their perceptions and understandings of STEM teaching and learning, they expressed a willingness to continue to learn and to engage with their new STEM peers and mentors. Many wanted their professional learning journey to continue and appeared willing to participate in future PD programs. The 12-month Academy appeared to have achieved its goals, but for the teachers, their journey may have just begun.

22.5 Conclusion

Results reveal statistically significant changes in teacher efficacy, outcome expectancies, and STEM career awareness with large effect sizes. Additionally, significant changes in teacher practices were reported with increased use of problem-solving through inquiry, working in small groups, increased engagement with content driven dialogue, and increased opportunities for student reasoning. Personal reflections offered by the teachers confirmed their increased efficacy in their ability to design and deliver effective STEM content that in turn increases student enthusiasm for learning. While teachers recognize these gains, they also indicate their need for continued collaboration among teachers on their teams as well as a need to stay connected with other colleagues and mentors to sustain and enhance their growth as STEM teachers. Teachers also expressed a need for more allotted time within their workday to design and plan integrated curriculum across the STEM subjects as well as further opportunities to upskill in other STEM disciplines.

While this study was limited to five STEM PD programs with 178 participants from 61 schools, we suggest the data from these teachers presents evidence of the impact of the program on teachers' practices, particularly through the eyes of the teachers. It would appear from teachers' survey responses and reflections that key features of the program lead to these changes—the collaborative nature of program design, the support of and feedback from academic mentors, the extended contact over 12 months, and the focus on STEM discipline knowledge, practices, and active learning—evidence supporting the advice from Darling-Hammond et al. (2017) and Rawolle et al. (2016). We realize that classroom observations are necessary to confirm the changes, and we realize further investigation of changes in our other programs would be needed to make further claims, but we are enthused by the outcomes to date and believe they offer us a unique opportunity to explore potential change in student STEM achievement and aspirations.

In this chapter, we report on the outcome of a year-long STEM PD program offered to both secondary and primary school teachers. Having designed our program around seven factors of high-quality, high-impact PD (Darling-Hammond et al., 2017) and using teachers' responses to survey data, there is evidence the goals of wanting to support teachers in implementing integrated STEM curriculum have been realized. However, we now need to analyze the student data from pre- and post-surveys to ascertain whether students' STEM attitudes and aspirations have improved. These data will help us to further understand the impact of our program and add to the body of research into integrated STEM curriculum in schools.

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