Chapter 4
Instructional Knowledge of STEM: The Voices of STEM Teachers in Taiwan

Yi-Fen Yeh and Ying-Shao Hsu

4.1 Background

Our changing world is one in which education is ever increasingly important. We need our future citizens to be ready for forthcoming challenges; therefore, contemporary education goals must focus on literacy (e.g., scientific literacy) and the development of survival skills (e.g., critical thinking, adaptability) that empower students to work, solve problems, and strive to be lifelong learners (Wagner, 2008). STEM—science, technology, engineering, and mathematics—education emphasizes interdisciplinary knowledge and skill development, higher order thinking through problem-solving, and connections between schooling and the world. As such, it is an area that attracts educators from a wide variety of academic subjects.

Interdisciplinary education is one of the foremost challenges for today's teachers. Students have reported that they learn far better from interdisciplinary teaching and learning rather than when a multidisciplinary pedagogy is employed (Jones, 2009). Teachers commonly receive a discipline-specific education via their academic majors, but those teachers who seldom engage in authentic inquiry may be less adaptable and receptive to interdisciplinary teaching and learning designs. Teaching interdisciplinary topics demands not only that teachers become proficient in related fields through self-learning and collaboration with other educators but also that they cultivate abilities like systemic and cross-linked thinking (Burandt & Barth, 2010). Teacher qualification is one priority that must be considered if we are to launch

Ying-Shao Hsu is a visiting professor at University of Johannesburg, South Africa.

Y.-F. Yeh (✉)
College of Teacher Education, National Taiwan Normal University, Taipei, Taiwan
e-mail: yyf521@ntnu.edu.tw

Y.-S. Hsu
Graduate Institute of Science Education, National Taiwan Normal University, Taipei, Taiwan
e-mail: yshsu@ntnu.edu.tw

Y.-S. Hsu and Y.-F. Yeh (eds.), *Asia-Pacific STEM Teaching Practices*,
https://doi.org/10.1007/978-981-15-0768-7_4

and sustain quality STEM education. Since various school levels (i.e., primary, middle, and high) have recruited teachers of science, mathematics, and technology but not necessarily engineering, we are interested in learning more about how teachers develop STEM curricula and how well they have developed their STEM instructional knowledge.

4.2 Developing Teachers for STEM Education

The emergence of STEM education is a response to the needs of a twenty-first-century workforce that can support cutting-edge industry development and citizens who can apply what they learned in school to solve life's problems (Caprile, Palmen, Sanz, & Dante, 2015; Charette, 2013). STEM literacy, the comprehensive goal of STEM education, is a composite construct of the knowledge and abilities that individuals rely on to address complex issues involved with various component topics (Bybee, 2013). Therefore, preparation of STEM teachers must first clarify the ultimate goals for STEM learners. Only then will we have a better understanding of (a) the knowledge and skills with which STEM teachers must be equipped and (b) how that acquisition can be facilitated.

4.2.1 Development of Instructional Knowledge for STEM

STEM education is an integrative approach that involves science, technology, engineering, and mathematics and also serves as a broader conceptual space not strictly limited to these four disciplines. Other possible areas may include disciplines such as the environment, economics, and medicine and creative artistic endeavors (Tarnoff, 2011; Zollman, 2011). Furthermore, scholars have suggested that STEM's greatest value is the purposeful integration of these disciplines into solving real-world problems (Labov, Reid, & Yamamoto, 2010). Bybee (2010) viewed STEM as an integrative subject where discipline-specific ways of thinking are combined and promoted, such as the identification of STEM issues, explanation of topics from STEM perspectives, and use of STEM information to solve problems. The literacy that a STEM education develops should also loop back to encourage lifelong learning effectiveness by strengthening learners' cognition (e.g., reflective abstraction), affection (e.g., self-regulation), and psychomotor skills (e.g., being an automatic learner) (Zollman, 2011). We take STEM literacy to be a metadisciplinary collection of knowledge, skills, and attitudes. Considering that STEM knowledge is usually topic based or interdisciplinary in nature, it may not be practical to expect the future workforce to develop full expertise in STEM for every unforeseen issue.

To help students develop this interdisciplinary literacy, teachers must be equipped with the skills of a particular profession and its related pedagogical skills. Previous literature has indicated that effective STEM teaching relies on content integration, a personal ability to solve problems innovatively or by conducting authentic inquiry, instruction in problem-solving, inquiry based in student-centered approaches, and the use of real-life contexts (Breiner, Harkness, Johnson, & Koehler, 2012; Chan, Yeh, & Hsu, under review; Ring, Dare, Crotty, & Roehrig, 2017; Wang, Moore, Roehrig, & Park, 2011). However, considering that teachers traditionally develop their instructional knowledge as domain or topic specific and even as personally developed, it can be quite difficult to reach a consensus regarding the definition of STEM pedagogical content knowledge (PCK). Chan et al. (under review) proposed a generic framework for practical instructional knowledge that is composed of four key domains: knowledge of assessment, pedagogy, curriculum, and students. Teachers effective in teaching STEM must develop related instructional ideas and experiences of varying degrees of specificity (i.e., domain specific and generic) and quality (i.e., quantity and concreteness).

Curriculum integration is ideal because knowledge that is relevant outside of schools lacks defined disciplinary boundaries. However, this holistic nature is not necessarily so when multiple disciplines are integrated in a contrived fashion (Beane, 1995). STEM education can be a useful solution encouraging cohesive integration and meaningful learning if "it encompasses real world, problem-based learning that links the disciplines through cohesive and active teaching and learning approaches" (English, 2016, p. 2). Developing such a curriculum demands that teachers either be knowledgeable about the topics being taught or able to communicate and work successfully with colleagues possessing different areas of expertise. Knowledge gaps may even appear among teachers of closely integrated disciplines such as science and mathematics (Stinson, Harkness, Meyer, & Stallworth, 2009).

Inequitable representations of the four STEM subjects involved are quite common in the literature. Often, curricula are science dominated or only two of the four disciplinary categories are emphasized, demonstrating the challenges in designing STEM curricula and opportunities for instructional knowledge development (Vasquez, Sneider, & Comer, 2013). How to encourage teachers to step out of their comfort zone to develop integrated curricula and sustain their professional development is critical to STEM teacher development, especially when topics are usually inquiry based and real-life contextualized. Teachers have to be motivated and willing to explore the target issues beyond the traditional disciplinary boundaries to develop curricula and instructional guidance that align with students' learning needs.

4.2.2 Teacher Community for Teacher Development

Discipline-specific teachers can engage in leading interdisciplinary courses like STEM by collaborating with educators of different subject specialization or by engaging in self-learning focused on interdisciplinary issues. Professional learning communities (PLCs), which are often self-initiated organizations, have become an excellent resource for teachers seeking to care for and learn from one another, embrace a vision beyond the scope of individual members, overcome difficulties in instruction, and induce change in practice and belief (Lambert, 2003; Tam, 2015). Attributes of successful PLCs include (a) being oriented toward and striving for better student learning progress; (b) continuously working together to find better teaching practices, enhance personal learning development, and encourage school improvement; and (c) aiming for evidence-based learning progress and seeking out areas of improvement (DuFour, 2004). However, traditional professional development (PD) efforts are focused on the needs of content area specialists; therefore, many PLCs are discipline based. In contrast, PLCs for STEM education must be interdisciplinary and, thus, should focus more on how teachers from different content areas and perspectives can be attracted from the greater community and learn to communicate and work well with other professions.

Project Lead the Way (PLTW), a large nonprofit organization, offers middle and high school STEM education programs (https://www.pltw.org/). Brophy, Klein, Portsmore, and Rogers (2008) argued that PLTW courses should engage students in support topics (e.g., the scientific process, engineering problem-solving, applications of technology), cross-disciplinary subjects (e.g., understanding how technology works with other tools, using mathematical knowledge to solve nonmathematical problems), and soft skills (e.g., effective communication, working with others). STEM teachers, whether they adopt an embedded or integrated approach (Roberts & Cantu, 2012), must step out of their respective comfort zones, teach beyond their familiar boundaries, and solve the problems that emerge during this process. Avery and Reeve (2013) recommended that PD for STEM teachers should include providing exemplar engineering design challenges, strengthening teachers' understanding of curriculum standards, learning evaluation methods for students' group performances, developing teachers' STEM PCK as integral to the profession through STEM lesson design, and engaging STEM concepts in instructional materials. Reynolds, Yazdani, and Manzur (2013) found that effective PD for STEM should engage teachers in accomplishing engineering-based research and projects on their own. Inclusion of these features would enhance the design of PLCs for STEM educators.

4.3 Method

The central focus of this chapter is documenting how subject-specific teachers developed STEM curricula and their level of instructional knowledge about STEM. Yin (2003) suggested that case studies are explanatory, exploratory, and descriptive in nature and are appropriate where a phenomenon within a real-life context or after an intervention can be investigated in order to reveal how and why the events occur or variables interact. We selected and documented the case of a PLC that had developed a series of STEM curricula and interviewed the teachers who comprised its membership.

4.3.1 Background of the Case

There were several reasons for choosing these teachers to serve as the PLC case study. First, they had spent at least 1 year developing thematic STEM-related courses as electives for Grades 11 and 12; two teachers had engaged even longer in related curriculum planning and implementation. Moreover, this PLC was formed to develop a STEM-related curriculum for the High-Scope III Project which aimed to "integrate emerging S&T [science and technology] of everyday life into their curriculum for fostering development of innovative S&T" (Ministry of Education, 2018, p. 9). The High-Scope Project is led by the Taiwan Ministry of Education, which offers grants to encourage middle schools, high schools, and colleges to develop topic-specific curricula for several disciplines or areas of study. It should be noted that the high school in this study had several PLCs; however, the others were not focused on STEM curriculum development.

The six participating teachers interviewed in the STEM PLC studied were all males and their backgrounds included physics, mathematics, technology, and the arts. They were teaching in a girls' high school (Grades 10–12) in the southern part of Taiwan. Recently, compulsory education in Taiwan has been extended to 12 years. Ninth graders in middle school have several paths to the high school they would like to attend. One path is to take the scholastic academic examination and achieve the required score for the desired school and the other path is a school-based selection process. Since the case study school was one of the oldest schools in that city and well known for its high-level student performance, the students in this school generally had a high aptitude for academics and most were likely to attend good universities.

4.3.2 Data Collection and Analysis

We used an interview protocol designed to reveal and document teachers' instructional knowledge of STEM categorized into four knowledge domains: curricula, students, instructional strategies, and assessment (Chan et al., under review). Each knowledge domain had two to three indicators (Table 4.1) from which the interview questions were developed (see Table 3.1 in Chap. 3).

Table 4.1 Codebook for instructional knowledge of STEM

Knowledge of curriculum (KC)	Knowledge of students (KS)	Knowledge of pedagogy (KP)	Knowledge of assessment (KA)
• Curriculum goals • Programs and materials • Identification of salient ideas	• Student abilities • Affective characteristics • Prerequisite knowledge • Difficulties or misconceptions	• Instructional representations • Instructional strategies	• What to assess • How to assess

Each interview lasted 30–60 min, prior to which all interviewees completed a background survey related to academic degrees and teaching experiences. All interview data were transcribed and coded through NVivo (https://www.qsrinternational.com/nvivo/home). The interview data were coded using the smallest meaningful episodes that were judged by knowledge indicators and the explicit (either general or topical) examples they included. Teachers' proficiency in each knowledge subset was evaluated using a consistent system where teachers would receive 1 point for a general example or a topical example. Scores of each knowledge category were composed of a score of general knowledge and a score of topical knowledge. These scores were calculated based on the overall response level they achieved for the indicators within a category over the numbers of corresponding indicators. That is, if it was a four-indicator category like KS, the accumulated score that a teacher might earn for KS-topical would be 4 at most if she gave many topical examples for each of the indicators within the KS. Likewise, the maximum score for the KS-general knowledge would be 4 if she provided 1 or more examples for each indicator. For fair comparisons across categories with different numbers of indicators, the accumulated score would be divided by the number of indicators in that category to provide a category average of general and topical knowledge: The KS-topical would need to be averaged by its four indicators. For example, a teacher would receive 1 point for a topical example within the indicator KP-1 (instructional representations) regardless of the frequency of specific examples she offered. If she did not offer any topical examples of KP-2 (instructional strategies), her final category score for KP-topical would be adjusted to 0.5. The comparisons of teachers' STEM knowledge in this study were made on the basis of knowledge categories, instead of indicators. Furthermore, grouping teacher knowledge into STEM-general or STEM-specific knowledge based on experience examples would enrich our discussions of teachers' instructional knowledge development.

4.4 Findings

We report the PLC profile from the aspects of the six teachers' backgrounds and brief curriculum descriptions, their performance in the four knowledge domains, and the cross-referenced PD and PLC needs.

4.4.1 Backgrounds of Teachers and Their Curricula

The case PLC was a school-based, curriculum development community, sharing the comprehensive goal of developing a series of STEM-related courses. The backgrounds of the six teachers being interviewed (e.g., subjects for which they were responsible, years of teaching experience) are shown in Table 4.2. When surveyed about their confidence in STEM teaching, all but T5 felt confident teaching STEM-related courses. T1 was the leader of the PLC and a key person for bringing in external support (e.g., writing grant proposals to support curriculum development, bringing in PD support from the university). He won a teaching award in 2018 from the Ministry of Education, which is viewed as the highest honor for teachers in Taiwan. The average amount of teaching experience for these teachers was 13 years, with a range of 5–21 years.

The PLC had developed a total of eight courses within the four themes (Fig. 4.1). Six of these eight courses were open to students who were interested in creating products or making things, whether they were oriented toward science or the liberal arts. Only two courses were more advanced and were offered solely to students who had chosen the science-oriented academic track. Taking the quadcopter course as an example, the teacher introduced aviation principles and related physical concepts, followed by engaging students to play with paper airplanes and simulate aviation in mobile phone apps. Students were later guided to manipulate DC electric motors through programming with Arduino (https://www.arduino.cc/), use 3D modeling to make simulated bamboo rafts, and control four DC motors' revolutions per minute (rpms) using both Arduino and cell phone apps. These activities allowed students to engage with concepts like transistors in technology, lift and angle of aviation in physics, rpms of DC motors used for quadcopter aviation, etc. After these introductory sessions, students physically experienced the application of inertia detectors on Segways® and small quadcopters, and applied acceleration and angular velocity to improve their respective quadcopter. Each group needed to remotely control the quadcopters, fly them through pathways in balanced aviation, and land them at an appointed location. Last, students visited the aerospace department at the local university to learn about different quadcopter applications in real life and gain experience controlling aerial drones. Their learning was evaluated via worksheets and tests and they also created an aerial photograph exhibition at the annual school celebration.

4.4.2 Teachers' Performance of STEM Instructional Knowledge

We evaluated the six teachers' STEM instructional knowledge based on their interview responses (Interview questions can be found in Chap. 3, this book). Their responses regarding the four knowledge domains are illustrated by type (i.e., general and specific knowledge) in Fig. 4.2. Certain patterns were identified from these teachers' performance.

Table 4.2 Teachers' subject backgrounds and STEM teaching experiences

	T1	T2	T3	T4	T5	T6
Academic degree	Ph.D.	Master's	Master's	Master's	Master's	Master's
Subject area (years of experience)	Mathematics (21)	Physics (5)	Information and computer education (11)	Arts (9)	Technology (19)	Mathematics (13)
STEM courses (years of experience)	Mathematical modeling, cloud computing, sleep control (2)	Arduino circuit implementation, program physics (1)	Game physics (1)	Incredible mechanisms (1)	Robotic sensing and control, theory of flight dynamics, control of quadcopters (5)	Artificial intelligence, trademark design (3)
STEM-related project experiences	High-scope III	High-scope III, STEM curriculum development	Game physics curriculum development in high-scope III	School actualization, mobile learning, high-scope III	High-scope III, school actualization, homogenized curriculum development	Artificial intelligence curriculum development for high-scope III
Confidence in offering STEM courses	Confident regarding innovations in technology and tools, aligning with educational reforms, teacher education, etc.	Fair level of confidence and is learning to do better	Self-assured, due to connections with personal discipline profession and from working within the PLC	Self-assured because "STEM plus Arts" is fun for students	Could do better when more experiences are gained	Self-assured after receiving good responses to leadership of science fairs and STEM teaching experiences
Notes	Teacher Award in 2018 (national level)					Frequently invited STEM education lecturer

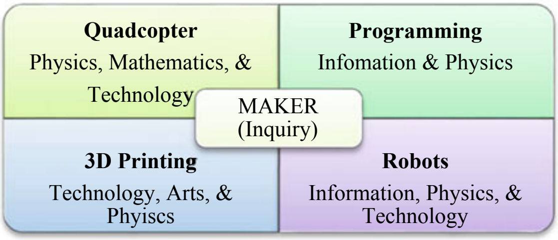

Fig. 4.1 The four themes of STEM-related courses developed by the professional learning community

Fig. 4.2 Teachers' interview performance in STEM instructional knowledge. Note that the vertical scales are different across the four knowledge components

4.4.2.1 Knowledge of Curriculum

Among the four domains, teachers' knowledge of curriculum (KC) seemed to be better developed in terms of both general and specific knowledge. However, we attribute the high-level knowledge scores to the teachers' responses about curriculum goals. They were the designers and practitioners of the courses, so they were well suited to explicate what they expected students to achieve, not only with general (G) but also specific (S) topical examples.

> T2: I think students should have the ability to analyze problems and engage in self-learning, since what we can teach them is very limited. They raise more questions under our appropriate guidance and take an active role in learning from those questions. … We cannot complement that part of knowledge. [KC-1G]

> T3: For this semester, my ultimate goal for students was to let them construct works of kinetic art. That is, throughout the history of the arts there has been art education, and artwork like this already exists. It can be found in sculpture. Gear theory has been used to make sculptures move, but they also have their own aesthetic value and paradigms. Then I started to look for … a physics teacher to collaborate with, hoping that he could help me take care of the structural mechanism of gears in physics. Students reviewed what they should have known and then tried to connect these two things. Therefore, I explicitly told my students that now that I'm an art teacher, in this course we will eventually get into art. Many sciences are involved in our art course. [KC-1S]

> T1: There could be many sources for projects. For example, I could design a brewer for coffee cups. The taste of the coffee is determined by the temperature, the warmth it keeps, and its water flow. [KC-3S]

4.4.2.2 Knowledge of Students and Pedagogy

Knowledge of student (KS) was the teachers' weakest knowledge domain, especially at the level of specific knowledge. T5 was the teacher with the highest total scores from the four domains; furthermore, T5 had developed his practical knowledge about specific issues across all domains. T2 and T4 were the second highest. The quote from T2 below illustrates his command of instructional knowledge about accommodating student learning needs with abundant topical knowledge that was transformed from his physics background and integrated with engineering applications. Based on the teachers' background survey, their experience with conducting projects focused on STEM curriculum development was a powerful indicator of their proficiency level in STEM instructional knowledge (Table 4.2).

> T2: Definitely we need to guide students, without a doubt. For this question [KP-2G], they came up with many sources for lift, but they only knew that it's lifting [KS-4S]. Then I guided them, such as by asking, "Why does it lift when the propellers rotate?" They thought that it could be wind. Then I continued, asking, "Then why do airplanes and fixed-wing airplanes lift up without propellers?" They answered, "They had wings." Then I used an analogy. "Helicopters have no wings, only propellers, so what's the correlation between the propellers and wings of planes?" [KP-2S]. Based on this guidance, they captured the idea that propellers are like the wings of planes. Planes have wings but they're fixed, while

[the rotating] propellers interact with wind [air]. Forces come from these interactions. So, I prompted them to consider whether the wind [air movement] was one reason contributing to lift [KP-2S]. They then started to draw a force diagram of wings and wind [air movement] and analyzed the pushing power [KP-2S]. After that, I asked them if the angles of the propellers were related or if angles could be another variable. [KP-2S]

4.4.2.3 Knowledge of Students and Assessment

Almost all of the teachers were experienced in teaching their respective subjects (i.e., the component STEM subjects) but were still developing their knowledge about and experience with STEM teaching. Therefore, it made sense that they had better levels of performance in terms of general knowledge. By comparison, knowledge of students (KS) and knowledge of assessment (KA) are types of instructional knowledge usually developed later along the PCK development continuum. KC and KP are more teacher-initiated anticipatory domains, while KS demands more reflective teaching experiences (e.g., noticing students' needs and cognitive development). Assessment is usually where teachers reflect and develop after they have the goals and instructional activities of the curricula designed.

T5: Assessments are the other difficulties for me. In terms of assessment … first, when it comes to groups, it makes me wonder how to … should I give the whole group the same score? Or how do I give different scores to 2 students in the same group? Of course their scores were ultimately based on the final results and their worksheets. And sometimes students may take official leaves and I don't feel like I can deduct their scores for that. I'm still looking for a proper way to deal with that. But generally speaking, my assessments were formative ones, mainly worksheets, since I don't want to give them any more academic pressure. [KA-2G]. … For students with special performance, like being my assistant in class or willing to answer questions frequently, I would offer them extra points. But I don't deduct students' points since I don't know them really well. [KA-1G]

4.4.3 Teachers' Perspectives Toward PLC

Since the PLC had been operating for 1–2 years for the purpose of curriculum development, information regarding how the teachers felt about the PLC offers valuable information for planning PD. Three strands were identified from their interview data: operation of the PLC, collaborative teaching, and self-learning (Table 4.3).

The PLC case could be viewed as a success if the shared goals were achieved, the participants grew in terms of their teaching, and a good working atmosphere was established among the participating teachers. A culture of co-learning and co-teaching also contributes to PLC's success. These six teachers prioritized the importance of self-learning and self-motivation, implying that they respected the other participants and were mutually supportive of each other. STEM classrooms that are open to interested faculty are friendly environments that accommodate both teachers

Table 4.3 Cross-referenced comments regarding critical aspects of a professional learning community

	PLC	Collaborative teaching	Self-learning
T1 (M)	• Fun to work with colleagues, which can be useful for future interdisciplinary learning	• We set courses as electives; I also invite teachers from different disciplines to co-teach courses	• STEM teachers are highly motivated in this area • As an academics-oriented school, teachers here have strong academic knowledge, which enables them to design interesting courses or activities. It would be another story if they were not motivated
T2 (S)	• Technology teachers help solve problems through practicality • Most courses are co-taught by two teachers, so we do our best to brainstorm different potential projects and enrich course content	• These courses are highly demanding with continuous problem-solving, so two teachers are needed. I may spend 10 min guiding a student who has a problem	• The two courses I offer are not closely related to my academic area (physics), so I spend an extensive amount of time self-learning • The most distinctive feature of STEM courses is teachers' self-learning rather than student learning. We all feel that we get back to the era of being students. We learn knowledge, solve problems, and build up something sufficient. It's quite fun during the process
T3 (T)	• We teachers in the PLC learn from each other and may consult previous course instructors for instructional ideas	• Better to prepare courses with colleagues from different fields since teachers will definitely face problems outside their profession	• Teachers should be open-minded and like to learn and try

(continued)

Table 4.3 (continued)

	PLC	Collaborative teaching	Self-learning
T4 (A)	• My colleagues like to help me when I find something I am not good at • Our current PLC works well because we are very close	• Our office is near the technology teacher's office, and we are good friends • T5 is a teacher full of educational idealism and he invites me to co-teach with him • I also work with T6, and we used GeoGebra to guide students to design logos	• STEM teachers should be interested in making things • T1 likes to build robots with LEGO®
T5 (T)	• Easier to learn from our physics and math teachers when we encounter problems in those areas	• We work with the professors and graduate students in the university's Maker Center Graduate students serve as tutors in our classes	• The Department of Aeronautics and Astronautics offered us a one-semester course to take
T6 (M)	• We are still developing courses for Grade 12. We've learned how others deliver courses and what concepts are engaged, which helps me to design courses	• I've co-taught with two other teachers. I became a student when the technology teacher was teaching programming. … Now the technology teacher is teaching with the art teacher (T3). T3 wants me to guide students to learn related math knowledge and then graphically design trade logos on computers. So I go to T3's classroom and learn with the students while T3 goes to mine	• STEM teachers are usually self-motivated, since everything starts with taking action

and students learning with one another. It is also important that school authorities support the co-teaching and co-planning system and establish related policies (e.g., by reasonably sharing teaching hours, arranging curriculum development hours, etc.). Successful co-teaching would require the course instructor to be the lead planner, especially when weekly topics and assessments are mutually conceptualized and negotiated as well as the teachers' expertise needs to be properly engaged (Chanmugam & Gerlach, 2013).

However, it should be noted that PD may not bring all positive impacts. There are barriers (e.g., administrative constraints, interpersonal issues, logistical or scheduling issues) or tensions attending PLCs (e.g., work pressure, shared learning, intrapersonal growth) in addition to the benefits of interdisciplinary PD (e.g., professional growth, enhanced trust and respect for colleagues, shared responsibility and collaborative problem-solving, collaborative research and co-teaching opportunities) (Miller & Stayton, 1998; Schaap et al., 2018). Both co-learning and co-teaching should be pursued, especially for interdisciplinary courses like STEM, since STEM knowledge and abilities are not only topic based but also demand flexibility in order to solve various problems in the process.

4.5 Final Remarks

This chapter discussed how STEM teachers who were subject specialists originally developed their instructional knowledge of STEM and how their PLC shaped their instructional knowledge and enabled them to develop a series of STEM courses. STEM education encourages students to complete projects or solve problems with different levels of complexity and difficulty. Teachers should consider if adequate difficulties are embedded in the STEM projects or problems since these life- and job-related tasks offer students good opportunities to deepen their knowledge, abilities, higher order thinking, and even expanding career options. This is why researchers have suggested that successful STEM education depends on teachers' pedagogy rather than content (Tytler, Osborne, Williams, Tytler, & Clarke, 2008) and that curriculum resources and assessments must be well planned to align with student needs and program goals (Kennedy & Odell, 2014). The teachers in this study may have developed good PCK in the specific subjects they teach, but they still need time to reflect on their STEM teaching experiences in order to transform their discipline-specific PCK into STEM PCK.

PD and PLC are critical to continuous teacher development—although the focus and format may be slightly different for teachers of single and interdisciplinary subjects. In the case examined here, experienced teachers united for the purpose of developing a series of STEM curricula. They knew their students and curriculum standards, so they preferred to develop motivating and inspiring courses. Drawing upon their mature PCK, they were enthusiastic about attending college-level engineering courses for a semester, learning with their fellow PLC participants, and collaborating in course design and teaching. These teachers ensured that they had prepared themselves until they were fully ready to deliver the designed STEM courses and able to guide their students. The leader of this PLC was important since he strategically brought in necessary resources (e.g., a topic-specific PD course offered by the university, curriculum development grants) and encouraged teachers from different fields to explore different topics and develop curricula collaboratively. To accommodate the many possibilities in STEM education, a sustainable PLC should have members with talents from different fields who are striving for a shared goal with full support from other stakeholders.

Acknowledgements This research is supported by the Institute for Research Excellence in Learning Sciences and the Higher Education Sprout Project of National Taiwan Normal University and sponsored by the Ministry of Education in Taiwan.

References

Avery, Z. K., & Reeve, E. M. (2013). Developing effective STEM professional development programs. *Journal of Technology Education, 25*(1), 55–69.

Beane, J. A. (1995). Curriculum integration and the disciplines of knowledge. *Phi Delta Kappan, 76*(8), 616–622.

Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics, 112*(1), 3–11.

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education, 97*(3), 369–387.

Burandt, S., & Barth, M. (2010). Learning settings to face climate change. *Journal of Cleaner Production, 18,* 659–665.

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher, 70*(1), 30–35.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. Arlington, VA: NSTA Press.

Caprile, M., Palmén, R., Sanz, P., & Dente, G. (2015). *Encouraging STEM studies for the labour market (Report for European Parliament's Committee on Employment & Social Affairs)*. Brussels, Belgium: European Union.

Chan, K., Yeh, Y.-F., & Hsu, Y.-S. (under review). A framework for examining teachers' practical knowledge for STEM teaching. In Y.-S. Hsu (Ed.), *Asia-Pacific STEM teaching practices: From theoretical frameworks to practices*. Singapore: Springer.

Chanmugam, A., & Gerlach, B. (2013). A co-teaching model for developing future educators' teaching effectiveness. *International Journal of Teaching and Learning in Higher Education, 25*(1), 110–117.

Charette, R. N. (2013, August 30). The STEM crisis is a myth. *IEEE Spectrum.* Retrieved from http://spectrum.ieee.org/at-work/education/the-stem-crisis-is-a-myth.

DuFour, R. (2004). What is a professional learning community? *Education Leadership, 61*(8), 6–11. Retrieved from http://www.ascd.org/publications/educational-leadership/may04/vol61/num08/What-Is-a-Professional-Learning-Community%C2%A2.aspx.

English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education, 3*(3). https://doi.org/10.1186/s40594-016-0036-1.

Jones, C. (2009). Interdisciplinary approach—Advantages, disadvantages, and the future benefits of interdisciplinary studies. *ESSAI, 7*, Article 26. https://dc.cod.edu/essai/vol7/iss1/26/.

Kennedy, T. J., & Odell, M. R. L. (2014). Engaging students in STEM education. *Science Education International, 25*(3), 246–258.

Labov, J. B., Reid, A. H., & Yamamoto, K. R. (2010). Integrated biology and undergraduate science education: A new biology education for the twenty-first century? *CBE Life Sciences Education, 9*(1), 10–16.

Lambert, L. (2003). *Leadership capacity for lasting school improvement*. Alexandria, VA: Association for Supervision and Curriculum Development.

Miller, P. S., & Stayton, V. D. (1998). Blended interdisciplinary teacher preparation in early education and intervention: A national study. *Topics in Early Childhood Special Education, 18*(1), 49–58.

Ministry of Science and Technology. (2018). *Ministry of science and technology: Republic of China (Taiwan)*. Taipei, Taiwan: Author. Retrieved from https://www.most.gov.tw/most_ebook/en/.
Reynolds, D., Yazdani, N., & Manzur, T. (2013). STEM high school teaching enhancement through collaborative engineering research on extreme winds. *Journal of STEM Education: Innovations and Research, 14*(1), 12–19.
Ring, E. A., Dare, E. A., Crotty, E. A., & Roehrig, G. H. (2017). The evolution of teacher conceptions of STEM education throughout an intensive professional development experience. *Journal of Science Teacher Education, 28*(5), 444–467.
Roberts, A., & Cantu, D. (2012). Applying STEM instructional strategies to design and technology curriculum. In *Proceedings of the Technology Education in the 21st Century*. PATT 26 Conference, Stockholm, Sweden, 111–118.
Schaap, H., Louws, M., Meirink, J., Oolbekkink-Marchand, H., Want, A. V. D., & Meijer, P. (2018). Tensions experienced by teachers when participating in a professional community. *Professional Development in Education*. https://doi.org/10.1080/19415257.2018.1547781.
Stinson, K., Harkness, S. S., Meyer, H., & Stallworth, J. (2009). Mathematics and science integration: Models and characterizations. *School Science and Mathematics, 109*(3), 153–161.
Tam, A. C. F. (2015). The role of a professional learning community in teacher change: A perspective from beliefs and practices. *Teachers and Teaching, 21*(1), 22–43.
Tarnoff, J. (2011, May 25). STEM to STEAM—Recognizing the value of creative skill in the competitiveness debate. *The Huffington Post.* Retrieved from http://www.huffingtonpost.com/john-tarnoff/stem-to-steam-recognizing_b_756519.html.
Tytler, R., Osborne, J., Williams, G, Tytler, K., & Clarke, J. C. (2008). *Opening up pathways: Engagement in STEM across the primary-secondary school transition. A review of the literature concerning supports and barriers to science, technology, engineering and mathematics engagement at primary-secondary transition*. Melbourne, Australia: Deakin University.
Vasquez, J. A., Sneider, C., & Comer, M. (2013). *STEM lesson essentials, grades 3–8: Integrating science, technology, engineering, and mathematics*. Portsmouth, NH: Heinemann.
Wagner, T. (2008). Rigor defined. *Educational Leadership, 66*(2), 20–24.
Wang, H.-H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-college Engineering Education Research, 1*(2), 1–13.
Yin, R. (2003). *Case study research: Design and methods*. Thousand Oaks, CA: Sage.
Zollman, A. (2011). Learning for STEM literacy: STEM literacy for learning. *School Science and Mathematics, 112*(1), 12–19.