Chapter 8
Teachers' SSI Professional Development in a Reflection-Based In-service Program

Wen-Xin Zhang and Ying-Shao Hsu

Abstract Teachers' professional development (PD) of teaching SSI has gained importance because the SSI-based interventions have demonstrated fruitful benefits for students' higher order thinking and the potential to promote connections between school science and real life. The contradictory and multiple perspectives in the SSI context presents many pedagogical challenges for teachers while teaching students how to discuss and deal with these issues in the classroom. Thus, we developed a PD program and used a systematic measurement to explore the teachers' discourse when they engaged in this experience. The case study invited 12 in-service teachers to participate; they were separated into three groups based on the teachers' backgrounds. All teachers' discourse in the group was collected and analyzed based on epistemic frame theory. The results indicated that (a) teachers' epistemic frames related to knowledge and skills were the most common forms of discourse and (b) engaging teachers in reflective practice was helpful for promoting their tacit discourse, including epistemology, and identity discourse. These findings suggest that an effective PD program needs to engage teachers in reflective practice in a long-term program and that interacting with teachers from diverse fields might be helpful for promoting their multidisciplinary perspective for teaching SSI.

Keywords Epistemic frame · Professional development · SSI education

8.1 Introduction

Many educational documents have stressed promoting students' scientific literacy and responsible research and innovation (Owen et al., 2012) due to the transformation from normal science to post-normal science (Eryasar & Kilinc, 2021; Kilinc et al., 2017). Rather than normal science, which focuses on detecting the causal-effect relationships between variables, post-normal science stresses the risks and uncertainties

W.-X. Zhang · Y.-S. Hsu (✉)
Graduate Institute of Science Education, National Taiwan Normal University, Taipei City, Taiwan
e-mail: yshsu@ntnu.edu.tw

Y.-S. Hsu et al. (eds.), *Innovative Approaches to Socioscitific Issues and Sustainability Education*, Learning Sciences for Higher Education,
https://doi.org/10.1007/978-981-19-1840-7_8

that need to be considered among science, technology, and society. Such a transformation shifts the educational goal to cultivating students' functional literacy in order to connect the scientific knowledge learned from school and real life (Chen & Xiao, 2021; Simonneaux & Simonneaux, 2008). The shifted education goals in science also resulted in the infusion of socioscientific issues (SSI) into classroom courses (Evagorou & Dillon, 2020; Levinson, 2013; Zeidler et al., 2019).

SSI are real-life problems caused by continued development and innovation in science and technology. These innovations not only bring conveniences to people, but also challenge values and insight moral and ethical uncertainty in society. Due to contradictions between science and society, people, as responsible citizens or scientists, are expected to make informed decisions about SSI considering multiple aspects (including science, environment, and society) at the personal, national, and global levels (Presley et al., 2013; Zeidler, 2014; Zeidler et al., 2019). SSI are inevitable and real-life problems that students need to be concerned about and prepared to deal with (Sadler, 2004). Thus, infusing SSI into the classroom can immerse students in authentic problems and prompt them to engage in higher order thinking practices to mediate contradiction between the issues.

Although many studies have explored the benefits of engaging students in SSI-based learning, the absence of studies on teachers' professional development (PD) regarding SSI teaching has been an issue of concern (Evagorou & Dillon, 2020). Several studies have demonstrated some design principles to help teachers' professional development for SSI teaching such as engaging teachers in co-design lesson practices (Friedrichsen, Ke et al., 2020), or reflective orientation practices (Leung et al., 2020). These studies used various tools (i.e., written survey and semi-structured interviews) to explore teachers' beliefs about SSI and their knowledge of SSI teaching. Few studies adopted assessment tools or techniques to systematically measure teachers' interacted discourse during the SSI PD program even though it is an important factor that influences teachers' PD for SSI teaching.

To address this gap, this chapter will introduce an SSI PD program to promote teachers' professional understanding and pedagogical practices in SSI teaching. We used an analytic epistemic frame (Shaffer et al., 2009; see Chap. 1 for details) to systematically examine in-service teachers' performance during the SSI PD program. Specifically, this study aimed to investigate what opportunities could be provided in the PD program to stimulate teachers' reformation of their epistemic frame for SSI teaching, including their skills, knowledge, value, identity, and epistemology. The results can not only help to elaborate our SSI PD program but also that of other teacher education programs. The research question guiding the current study is: What are the effects of the different activities of the PD program on teachers' epistemic frame?

8.2 Literature Review

8.2.1 The Teachers' SSI Teaching and Effective SSI PD Programs

Nielsen et al. (2020) addressed three main research themes of SSI teaching in teacher education. The first theme refers to how teachers' backgrounds and beliefs affect their uptake and quality of SSI teaching. Several researchers have indicated that teachers' background (including knowledge, skills, and attitude) might influence how they enacted SSI in their classrooms (Kilinc et al., 2017; Leung, 2021; Saunders & Rennie, 2013). Tidemand and Nielsen (2017) found that their participants, biology teachers in Denmark, generally held a content-centered belief of SSI and infused SSI into their classroom as a vehicle to teach factual content. Kilinc et al. (2017) found that teachers' resistance to conducting dialogic discourse in the SSI teaching practice was likely because of their worries about unsatisfactory knowledge related to the multiple aspects of the central issues and socioscientific factors.

The second theme is related to effective SSI teaching. The complex nature of the central issues and the multiple goals of teaching mean that SSI teaching usually incorporates and considers various teaching focuses. Generally, teachers are expected to build SSI teaching with compelling, controversial, and ill-structured problems that involve multiple perspectives (Friedrichsen, Sadler et al., 2020; Owens et al., 2019; Presley et al., 2013; Zeidler, 2014). This requires the use of various scaffolds/tools/strategies to present the issue in contextualized and authentic ways (Furman et al., 2020), to engage students in higher order thinking practices, and to build a safe communicated environment for students' negotiation and discussion of their perspectives on the SSI (Sadler, 2011; Topçu et al., 2018).

The third theme involves effective SSI PD programs and education needed to improve teachers' or student teachers' uptake and quality of teaching. Friedrichsen and her colleagues engaged teachers in a collaborative professional development environment to co-design and enact the SSI teaching practices (Friedrichsen, Ke et al., 2020; Friedrichsen, Sadler et al., 2020). They identified three types of profiles that teachers would hold after an appropriate PD activity, namely embracers, dismissers, and explorers. Garrido Espeja and Couso (2020) conducted their PD program with a long-term process (two months) and prompted pre-service teachers in a practice cycle of design-implementation-reflection (D-I-R). They found that teachers' experience in the D-I-R program improved the quality of their designed lesson plans, including what issues teachers selected, the scaffoldings they used to support students' SSI learning, and the assessment they employed to assess students' learning of the SSI topic. These studies provide insights that long-term PD, collaborative design and enactment of SSI teaching practice, and engagement of reflection practice seem to play a positive role in effective SSI PD programs.

8.2.2 Epistemic Frames for Professional Teaching

Epistemic frame theory describes a mechanism that learners can adopt to effectively transfer their understanding of the original context to a new situation (Shaffer, 2006a, 2006b). The epistemic frames included five elements: skill, knowledge, value, identity, and epistemology. These elements had interconnected relationships and then co-influenced an individual's professional practice and innovative thinking.

SSI teaching practice is also professional practice. Teaching is a complex professional practice in which educators (including novices and experts) engage students in various learning activities to construct their understandings of a subject. The professional practice "that involves uncertainty…therefore, requires decision and judgment" (Shaffer, 2006b, p. 95). Therefore, teachers, as professionals, are expected to make a series of pedagogical decisions and reflect on the previous decisions to support students' engagement in a more effective and meaningful learning context (Phillips et al., 2021). Making pedagogical decisions requires a professional to effectively synthesize their knowledge, skills and practice, beliefs and values, and their teaching goals to plan and enact the teaching practices, which were related to the five elements mentioned above. Therefore, in an SSI PD program, teachers are learners who need to construct their understanding of SSI to make pedagogical decisions to teach SSI in their classroom. Specifically, SSI PD programs need to cultivate teachers' SSI pedagogical stance, which implies reconceptualizing their epistemic frame towards that of professionals.

Furthermore, improving the epistemic frame is a process of enculturation to enhance a person's naïve understanding of the epistemic frame in a particular community of practice (Jones, 2019, June). Through the interaction with other community members, newcomers become community members, continue to develop their expertise, and form their epistemic frame, which can be transferred to different contexts. Therefore, the successful construction of teachers' epistemic frame relies on how and what the members in the community discuss, interact, and communicate with each other (Bressler et al., 2019).

The literature review provides the insights into SSI teaching practices with multi-pedagogical principles that require teachers to make pedagogical decisions based on their beliefs and backgrounds and various pedagogical strategies/tools to engage students in meaningful, effective ways of knowing about SSI and related practices. However, these requirements might be a burden for teachers because of their lack of understanding of SSI teaching, their skills to design and enact SSI teaching plans, and their beliefs or epistemology of SSI teaching. Obviously, teachers need an effective PD program to improve their professional awareness and insight into teaching SSI that overcome the burden and challenges. Several studies indicated that long-term PD (Garrido Espeja & Couso, 2020), collaborative design of SSI teaching practice (Friedrichsen, Ke et al., 2020; Friedrichsen, Sadler et al., 2020), and reflection practice (Leung, 2021; Leung et al., 2020) were positive principles in improving teachers' professional knowledge and practices of SSI teaching. Notable gaps still exist as there is no systematic assessment to measure the effects of pre-service and

in-service PD programs. SSI teaching is a complex practice and teachers should take various pedagogical considerations into account. Hence, the PD program usually consists of several activities with different objects to improve teachers' PD. It is required to examine these different activities, which were expected to bring different effects on reforming teachers' epistemic frame, and even understanding how the tasks interact with one another. In addition, to get insights from the viewpoints of the learning community, it should be explored that teachers' interacted discourse in the learning community plays an essential role in reforming their epistemic frame of SSI teaching. In order to address these gaps, this study used the epistemic frame theory (Shaffer et al., 2009), which is introduced in Chap. 1, to explore what and how a PD program shapes teachers' understanding of SSI teaching through social interaction in a small learning community composed of an expert teacher and some native teachers. The investigation of what and how group members interacted with each other in the PD program, especially those different activities, would be used to refine our PD program and provide some insights for other teacher education programs.

8.3 Method

8.3.1 Context of Study

The new curriculum standards in Taiwan stress cultivating students' abilities to solve problems found in their real lives. Although many in-service teachers have perceived the potential of teaching SSI to promote students' scientific literacy, most of them have no idea of how to integrate SSI into their school courses (Nielsen et al., 2020; Tidemand & Nielsen, 2017). Thus, our research team collaborated with many governmental organizations and teachers' learning communities in Taiwan, such as the Earth Science Education Resource Center and the Ocean Education Resource Center, to prepare in-service teachers' SSI teaching practice via a workshop. Due to the practical challenges and time limitations, this study developed a short-term PD program (five hours) to improve teachers' SSI teaching. The SSI PD program was conducted in a workshop that comprised three stages, namely, the understanding of SSI teaching, experiencing and reflecting on an SSI-based learning module, and designing an SSI lesson (Table 8.1 outlines the activities and time allotments). The first stage summarizes how the research team introduced a lecture regarding SSI teaching and the socioscientific issues-based learning (SSIBL) framework (Levinson, 2018) to the in-service teachers (Activity 1). The purpose in this stage was to improve teachers' understanding of SSI and pedagogical strategies for teaching SSI via some particular examples of teaching practices based on the SSIBL framework.

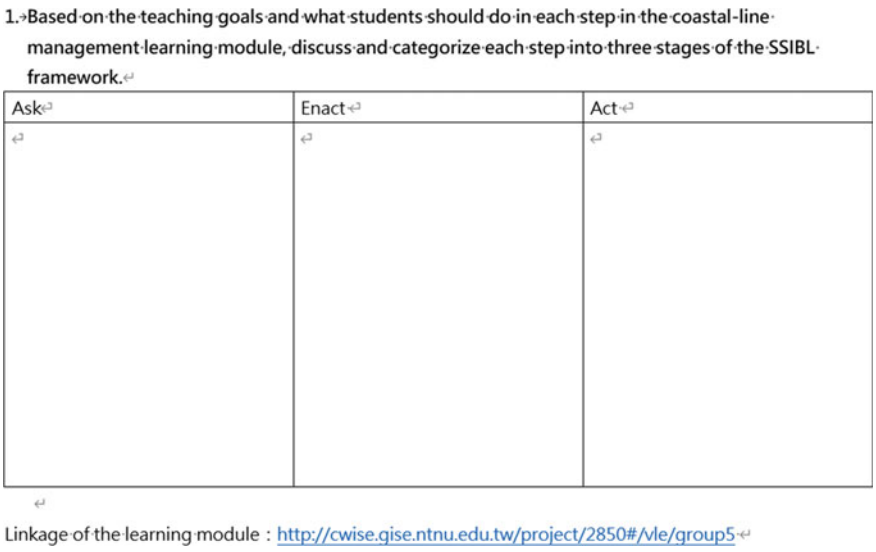
The second stage comprised two activities (Activity 2 and 3), which were designed based on reflective practice. Farrell (2012, p. 7) argued that the reflection-on-practice enables teachers to stop and look "where they are at that moment and then decide where they want to go (professionally) in the future". Reflection can help teachers

Table 8.1 SSI PD program

Stage	Activity	Time (h)
Stage 1: Understanding the SSI	*Activity 1* The research team provides a lecture to introduce SSI-based teaching and learning to the in-service teachers about the properties of SSI and pedagogical strategies via a particular framework of SSI teaching, the SSIBL	1
Stage 2: Experiencing and reflecting on an SSI-based learning module	*Activity 2* Teachers experienced being students while collaboratively engaging in an SSI-based learning module	1
	Activity 3 Teachers were asked to analyze and reflect on the SSI-based learning module based on what they had learned in the first activity	1
Stage 3: Designing an SSI lesson	*Activity 4* In-service teachers co-designed their SSI lessons	2

to connect their skills, knowledge, and epistemology. Through this process, teachers have opportunities to learn how to think and act in innovative ways and to develop their epistemic frame of a professional practice simultaneously (Burhan-Horasanlı & Ortaçtepe, 2016; Schön, 1983; Shaffer, 2006b). Rooted in this perspective, the goal of the second stage is engaging teachers in reflective practices. The teachers first experienced as students a particular SSI-based learning module (as presented in Chap. 4) related to coastline management (Table 8.1 Activity 2). Then, in Activity 3 (including three discussion tasks, some examples as shown in Figs. 8.1 and 8.2), teachers were required to collaboratively analyze and reflect on the pedagogical strategies used in the SSI teaching practices. They were provided guiding questions in this activity to promote their discussion and reflection (Figs. 8.1 and 8.2 present the guiding questions in detail).

The third stage (Activity 4) requested the teachers to co-design a new SSI lesson. We asked each group to select an appropriate issue based on their understanding of the nature of SSI. Then, they were guided with a three-stage framework of SSIBL, including ask, enact, and act (Levinson, 2018), to arrange their SSI lesson collaboratively.


1. Based on the teaching goals and what students should do in each step in the coastal-line management learning module, discuss and categorize each step into three stages of the SSIBL framework.

Ask	Enact	Act

Linkage of the learning module : http://cwise.gise.ntnu.edu.tw/project/2850#/vle/group5

Fig. 8.1 Task 1 of Activity 3

8.3.2 Participating Teachers

A total of 12 in-service teacher volunteers participated in the study, including three experienced teachers who had conducted an SSI-based learning module (used in the second stage in Table 8.1) in their classroom and nine in-service teacher volunteers who were interested in implementing SSI in their classrooms. These teachers' experience of teaching ranged from five years to more than 20 years. One taught in special education, three taught social studies including geography and citizenship studies, and five taught earth science. All of the experienced teachers taught earth science.

This study adopted the heterogeneous grouping approach to categorize these 12 teachers into each group to increase the discussion and negotiation across different disciplines based on their experience and teaching subjects. Thus, in each group, one experienced and three inexperienced teachers who teach different subjects were grouped to complete the PD program collaboratively. It should be noted that due to the time limitation, in Activity 2 (Table 8.1), at the beginning we asked experienced teachers to introduce the learning module to other members. The new teachers were encouraged to propose questions about the learning module to help the experienced group leaders to clarify it quickly and effectively.

2. Compare the SSI-based learning module and the new curriculum standards in Taiwan

- What learning content (subject knowledge) would students need when they engaged in the learning module?

- Based on the teaching goals and what students should do in each step, what learning performance (competencies) shown in curriculum standards can be improved?

steps	The tasks students should do	The literacy in curriculum guideline.
1.1.1	Reasoning the factors may influence the coastal-line change.	
1.1.2	Inquiring the information presented in the software and identifying the dilemma problems	
1.2.1	Inquiring about the software and Understanding 4 coastal-line protection engineering via the software.	
1.3.1	Weighting 4 coastal-line protection engineering.	
1.3.2	To design an appropriate proposal to manage the coastal-line change.	
1.4.3	Predicting all positive and negative influences of the proposal.	
1.4.4	Debating the proposal.	
1.5	Reviewing and revising the learning process	
1.6	Peer evaluation of the proposal.	
1.7	Summarizing and responding to peers' comments	

Fig. 8.2 Task 2 of Activity 3

8.3.3 Data Collection and Analysis Process

This study was based on the assumption that teachers' epistemic frame of understanding can be changed via interaction with other people. Thus, each group's verbal discourses were audio-recorded when teachers discussed and negotiated in the second and third stages of the PD program (Table 8.1). All verbal audio-recordings were transcribed and used as the primary data source in further analysis. The discourse was segmented by utterance defined as when a teacher expressed a single meaningful sentence during group discussion. We developed a coding rubric in an iterative process to analyze the transcriptions and to establish teachers' epistemic frame for SSI teaching. First, we generated the coding rubric based on the epistemic frame theory comprised of five codes for the elements: skills, knowledge, identity, values, and epistemology. Then, three coders read a randomly selected transcript independently and checked that the a priori codes were appropriate for this transcript. Based on the discussion to refine and confirm the list of codes and coding strategies, the finalized coding rubric was established as shown in Table 8.2.

Table 8.2 Coding rubric of the epistemic frame for SSI teaching

Element	Definition	Examples
Skills: the practices developed within a community	Any utterance regarding teaching strategies and enacting SSI teaching, including designing the material, curriculum, and constructing the learning environment	We then used this activity to check and measure their understanding of coastal engineering (GP-A2-U 11)
Knowledge: the understandings shared by people in the community	Any utterance related to the understandings used in teaching SSI, such as understandings of SSI, understandings of teaching strategies for SSI, the knowledge of their students, and prediction of their students' performance	This activity is a kind of assessment to measure students' concepts after the activity (GP-A2 U 15)
Identity: the ways that community members see themselves	Any utterance that refers to how teachers see themselves in teaching SSI, including their personal teaching goals for SSI teaching and personal properties	I don't understand this. I lack knowledge [in this field]. I just guess there are land crabs there, but I don't know if it [engineering] benefits them [the land crabs] (GP-A2-U 347)
Values: the beliefs community members hold	Any utterance expressing the beliefs or orientation the teachers hold about teaching SSI, including the perceptions, necessities and essentials of SSI teaching	[I think that] Teachers must focus on different points based on their students' properties and backgrounds. They refined the learning module for their students (GP-A2-U 71)
Epistemology: the particular ways of thinking about or justifying teaching actions	Any utterance related to reasoning or justifying their decision about strategy use and practice, especially the effectiveness of the teaching strategies or practices	I heard that Ms. Liu conducted this module in half of the semester because she spent much time constructing a safe environment and actively preparing her students to engage in discussions. As I see it, her students showed better performance than mine (GP-A2-U 87)

Note A label behind an example means: group-activity-utterance number

The skill element is about pedagogical strategies teachers used to plan, design, and enact the learning activities, material, and environment. The knowledge element is related to teachers' understanding of the instructional strategies, assessment, goal, and objectives of the SSI curriculum, and students' background relevant to SSI learning. The identity element refers to what teachers see in teaching SSI and that the value connects to teachers' personal beliefs and orientation of SSI teaching. The

epistemology element is usually related to teachers' pedagogical decisions or justification of the SSI teaching. A random selection of a group's discourse in the third stage was used to confirm the inter-rater reliability of the coding rubric. The pair-wise agreement of the three coders demonstrated an acceptable value range from 0.94 to 0.99.

Then, this study employed descriptive analysis (including frequency and percentage in Activity 2–4) and Chi-square analysis to compare the percentages of each element across activities to explore the in-service teachers' epistemic frame in the SSI PD program.

8.4 Results

This study found that all groups exhibited 1,097 utterances related to the epistemic frame of SSI teaching in the SSI PD program (326, 365, and 406 in each teacher PD group). Teachers' discourse regarding the five elements of the epistemic frame from Activities 2, 3, and 4 is presented in Table 8.3. It should be noted that we calculated an hourly rate in the three activities 2–4 because the teachers had more time to engage in Activity 4 (2 h as shown in Table 8.1) than others. When considering the time factor, teachers had the maximum discourse per hour in Activity 3 compared with the other two activities (hourly rate in Activity 2–4 is 163, 418, and 258, respectively). Also, the teachers focused most of their utterances on the knowledge about SSI teaching in all activities (396). The second largest number of utterances was related to skill (203.5), in which teachers expressed how they would enact SSI-based teaching for their students. Furthermore, 115 utterances indicated that teachers tried to explain or justify their pedagogical strategies usage and practice (epistemology element) whereas the participating teachers expressed 95.5 utterances related to their evaluation and appraisal of the SSI teaching or the pedagogical strategies employed in their teaching practice (value element). The identity-related discourse was the relatively minor utterance discussed in the SSI PD program (29).

Table 8.3 The Chi-square analysis of teachers' epistemic frame in three activities

		Activity 2		Activity 3		Activity 4		χ^2	*df*	*p*
	Total	*f*	%	f	%	*f*	%			
Skill	203.5	53	26	80	39	70.5	35	5.56	2	0.062
Knowledge	396	53	13	215	55	128	32	99.59	2	< 0.001
Identity	29	11	38	15	52	3	10	7.72	2	0.021
Value	95.5	25	26	40	42	30.5	32	3.56	2	0.168
Epistemology	115	21	18	68	59	26	23	34.78	2	< 0.001
Total	839	163	19	418	50	258	31			

Note The number of frequencies above was the average of frequencies per hour

To explore the function-specific discourses across the PD program, we compared teachers' discourses in three activities with different purposes by applying Chi-square analysis to the average frequencies per hour for each of the five epistemic elements. For this analysis, we assumed that the expected frequencies in the three activities were equal because we did not have any previous evidence to know the exact expected value in the three activities. Based on this assumption, the significant results indicated there was a significant frequency between these activities. Table 8.3 summarizes the Chi-square results, which indicated that the average frequencies (per hour) of teachers' discourses were significantly different amongst the three activities in three elements, including knowledge ($\chi^2(2) = 99.59, p < 0.001$), identity ($\chi^2(2) = 7.72, p = 0.021$) and epistemology ($\chi^2(2) = 34.78, p < 0.001$). The percentages shown in Table 8.3 indicate that teachers' knowledge, identity, and epistemology discourses in Activity 3 were higher than other activities.

8.5 Discussion

This study found that teachers paid more attention to talking about knowledge and skills of SSI teaching than the other three epistemic elements when they attended the SSI PD program. The identity, value, and epistemology discourses were expressed much less in the activities. This finding revealed that the PD program was successful in terms of evoking teachers' thoughts about SSI teaching knowledge and skills but should make more effort to help teachers to consider the value, identity, and epistemology of SSI teaching. Besides, the comparison of the different discourses of epistemic frames in the workshop activities revealed that teachers had significant discrepancies in their discourse across the three activities. Teachers showed more discourse related to knowledge, identity, and epistemology than expected in specific reflection activity (Activity 3).

After rethinking the design of the PD program, the lack of directed guidance and time limitation might be the factors that affected teachers' discourse. It is not surprising that teachers showed more discourse regarding knowledge and skills in the PD program. Although this study provided a short-term PD program to in-service teachers, concreate teaching material allowed the teachers to imagine what and how to design an SSI lesson and then promote their knowledge and skill discourses in the PD program. This finding is similar to that of Bayram-Jacobs et al. (2019) who demonstrated that a short-term PD program could successfully improve teachers' knowledge of SSI teaching.

However, this study also found that teachers' discourses related to value, identity, and epistemology were fewer. It implies that these implicit elements are hard to express in words (Fuchs, 2001; Polanyi, 1966) if an individual is not required to talk about them explicitly. Thus, prompting teachers' deliberate discourse related to these tacit thoughts was crucial to stimulating them to engage in deep and sophisticated discussion about SSI teaching. Engaging teachers in reflection-on-practice may be one good choice. The findings from Chi-square analysis in this study that the

teachers demonstrated discourses of epistemic frame differently between Activity 2, Activity 3, and Activity 4 seems to confirm our speculation. We found that teachers' discourses referring to knowledge, identity, and epistemology had more than expected frequencies when they engaged in Activity 3, a reflective practice. Reflective practice can help teachers conduct a series of systematic problem-solving processes that they need to deliberate their pedagogical actions and justifications (Dewey, 1933). These deliberate thoughts prompt the teachers to stop their activity and then detect their cognitive condition of SSI teaching (Farrell, 2012). Hence, in these reflection processes on pedagogical decisions and justification, teachers have opportunities to externalize their implicit thoughts (identity, value, and epistemology) and then elaborate on them.

The second factor that might help explain teachers' unsatisfied discourses in the PD program was the time limitation, especially the low frequencies of tacit elements (value, identity, and epistemology). Nielsen et al. (2020) indicated that long-term PD programs for teachers' SSI teaching are necessary to secure the uptake and quality of SSI teaching. As shown in the Friedrichsen, Ke et al. (2020) study, a long-term program over 6 months in which teachers were asked to co-design their SSI unit and encouraged to enact it in their classroom demonstrated its value. Many benefits were gained for teachers through this collaborative design of SSI teaching. We argue the necessity of long-term PD because the complicated nature of SSI is a challenge for teachers. Many studies have indicated that SSI learning is a complex and challenging context for students who need effective multiple scaffolds or guidance, such as collaborative learning (Zhang & Hsu, 2021) and metacognitive prompts (Hsu & Lin, 2017). To effectively infuse SSI in the classroom, teachers should understand the nature of SSI and how to deal with it based on their higher order thinking. They then need to transfer these epistemic understandings to design and enact the teaching practice. These complex, challenging processes imply that the profession of SSI teaching cannot be improved with short-term workshops because teachers need not only to construct their knowledge of SSI teaching but also the value, identity, and epistemology of SSI teaching, just as Jones (2019, June) indicated that improving teachers' epistemic frame is an enculturation process. The construction of a professionally epistemic frame needs long-term interactions with other community members with diverse backgrounds and expertise.

8.6 Conclusion and Limitations

This study aimed to promote teachers' PD in SSI education. We sought a practical and systematic assessment to explore teachers' interacted discourse during the SSI PD program based on the epistemic frame theory. The results indicated that the short-term PD program effectively promoted teachers' epistemic discourse, especially in the knowledge and skills elements. However, teachers' discourse related to tacit elements such as value, identity, and epistemology were unsatisfied. According to the findings of this study, we assumed that an effective PD program needs to engage teachers in

deliberate discussion such as reflection-on-practice to promote teachers' discourse related to those tacit elements. Burhan-Horasanlı and Ortaçtepe (2016) suggested that there are three types of reflective practices: reflection on/in/for. This study prompted teachers to reflect-on-action (i.e., look at previous experience) and reflect-in-action (i.e., awareness in the moment). Reflect-for-action means that teachers consider the implementation of what they learn at the moment *in the future*. We assume that reflection for action helps teachers transfer their acquired knowledge and skills to a new situation. Thus, PD program developers should consider infusing reflection-for-action practice into their programs and future research.

A long-term PD program is necessary to improve teachers' pedagogical knowledge about and practice in SSI education. Due to the practical challenges and time limitations, this study developed a short-term PD program to improve teachers' PD of SSI teaching. Although Bayram-Jacobs et al. (2019) indicated the positive effects of a short-term PD program on teachers' pedagogical content knowledge (PCK) of SSI teaching, this study demonstrated that the short-term PD program maybe not be valid for those more tacit elements especially value, identity, and epistemology. A possible solution could be a further activity that asks teachers to implement the SSI lesson they designed in the classroom. This could provide an operational response to teachers' SSI lessons and promote their reflection on SSI teaching. Several cycles of experiencing SSI lessons, designing SSI lessons, and implementing SSI lessons could be conducted to elaborate teachers' PD of SSI teaching.

This study demonstrated a primarily systematic analysis to examine the effects of a PD program on teachers' epistemic frame of SSI teaching. Further analytic techniques might be required to explore the dynamic, temporal, and sequential features of how teachers reframe their epistemic frame of SSI teaching. It should be noted that we assumed that each activity operated independently of the other to explore the effect of different activities on teachers' SSI PD. The dynamic effects of different activities can be explored in future research to investigate the cumulative effects on promoting teachers' SSI PD (i.e., teachers' productive discourse on Activity 3 might be due to the effects of Activity 1 and Activity 2). In addition, it is not enough to just categorize teachers' discourses about SSI teaching into five elements. For example, teachers' knowledge of SSI teaching can be further divided into several categories. Studies related to teachers' PCK of SSI teaching proposed diverse expertise, including instructional strategies, assessing students' SSI learning, goal, and objectives, students' prior knowledge, and performance (Bayram-Jacobs et al., 2019; Han-Tosunoglu & Lederman, 2021; Lee, 2016). Further analytic techniques can be used for exploring teachers' epistemic frames in detail. For example, the epistemic network analysis is an analytical technique that can be utilized to capture the dynamic, temporal, and sequential features when teachers construct and refine their epistemic frames (Bressler et al., 2019; Csanadi et al., 2018).

Acknowledgements This study is supported by the Ministry of Science and Technology, Taiwan, under grant number MOST 107-2511-H-003-014-MY3, MOST 110-2511-H-003-025-MY3, and the National Taiwan Normal University (NTNU) within the framework of the Higher Education Sprout Project by the Ministry of Education (MOE) in Taiwan.

References

Bayram-Jacobs, D., Henze, I., Evagorou, M., Shwartz, Y., Aschim, E. L., Alcaraz-Dominguez, S., Barajas, M., & Dagan, E. (2019). Science teachers' pedagogical content knowledge development during enactment of socioscientific curriculum materials. *Journal of Research in Science Teaching*, *56*(9), 1207–1233. https://doi.org/10.1002/tea.21550

Bressler, D. M., Bodzin, A. M., Eagan, B., & Tabatabai, S. (2019). Using epistemic network analysis to examine discourse and scientific practice during a collaborative game. *Journal of Science Education and Technology, 28*(5), 553–566. https://doi.org/10.1007/s10956-019-09786-8

Burhan-, E., & Ortaçtepe, D. (2016). Reflective practice-oriented online discussions: A study on EFL teachers' reflection-on, in and for-action. *Teaching and Teacher Education, 59*, 372–382. https://doi.org/10.1016/j.tate.2016.07.002

Chen, L., & Xiao, S. (2021). Perceptions, challenges and coping strategies of science teachers in teaching socioscientific issues: A systematic review. *Educational Research Review, 32*, Article 100377. https://doi.org/10.1016/j.edurev.2020.100377

Csanadi, A., Eagan, B., Kollar, I., Shaffer, D. W., & Fischer, F. (2018). When coding-and-counting is not enough: Using epistemic network analysis (ENA) to analyze verbal data in CSCL research. *International Journal of Computer-Supported Collaborative Learning, 13*(4), 419–438. https://doi.org/10.1007/s11412-018-9292-z

Dewey, J. (1933). *How we think: A restatement of the relation of reflective thinking to the educative process.* Heath & Co Publishers.

Eryasar, A. S., & Kilinc, A. (2021). The coherence between epistemologies and SSI teaching: A multiple-case study with three science teachers. *Science and Education*, 1–25. https://doi.org/10.1007/s11191-021-00200-7

Evagorou, M., & Dillon, J. (2020). Introduction: Socio-scientific issues as promoting responsible citizenship and the relevance of science. In M. Evagorou, J. A. Nielsen, & J. Dillon (Eds.), *Science teacher education for responsible citizenship* (pp. 1–11). https://doi.org/10.1007/978-3-030-40229-7_1

Farrell, T. S. C. (2012). Reflecting on reflective practice: (Re)visiting Dewey and Schön. *TESOL Journal, 3*(1), 7–16. https://doi.org/10.1002/tesj.10

Friedrichsen, P. J., Ke, L., Sadler, T. D., & Zangori, L. (2020). Enacting co-designed socio-scientific issues-based curriculum units: A case of secondary science teacher learning. *Journal of Science Teacher Education*, *32*(1), 85–106. https://doi.org/10.1080/1046560X.2020.1795576

Friedrichsen, P. J., Sadler, T. D., & Zangori, L. (2020). Supporting teachers in the design and enactment of socio-scientific issue-based teaching in the USA. In M. Evagorou, J. A. Nielsen, & J. Dillon (Eds.), *Science teacher education for responsible citizenship* (pp. 85–99). https://doi.org/10.1007/978-3-030-40229-7_6

Fuchs, T. (2001). The tacit dimension. *Philosophy, Psychiatry, and Psychology, 8*(4), 323–326. https://doi.org/10.1353/ppp.2002.0018

Furman, M., Taylor, I., Luzuriaga, M., & Podestá, M. E. (2020). Getting ready to work with socio-scientific issues in the classroom: A study with Argentine teachers. In M. Evagorou, J. A. Nielsen, & J. Dillon (Eds.), *Science teacher education for responsible citizenship* (pp. 133–151). https://doi.org/10.1007/978-3-030-40229-7_9

Garrido Espeja, A., & Couso, D. (2020). Introducing model-based instruction for ssi teaching in primary pre-service teacher education. In M. Evagorou, J. A. Nielsen, & J. Dillon (Eds.), *Science teacher education for responsible citizenship* (pp. 153–171). https://doi.org/10.1007/978-3-030-40229-7_10

Han-Tosunoglu, C., & Lederman, N. G. (2021). Developing an instrument to assess pedagogical content knowledge for biological socioscientific issues. *Teaching and Teacher Education*, *97*. https://doi.org/10.1016/j.tate.2020.103217

Hsu, Y.-S., & Lin, S.-S. (2017). Prompting students to make socioscientific decisions: Embedding metacognitive guidance in an e-learning environment. *International Journal of Science Education, 39*(7), 964–979. https://doi.org/10.1080/09500693.2017.1312036

Jones, T. (2019, June). Creation of an engineering epistemic frame for K-12 students (fundamental). *CSCL 2013 Conference*, Madison, WI.

Kilinc, A., Demiral, U., & Kartal, T. (2017). Resistance to dialogic discourse in SSI teaching: The effects of an argumentation-based workshop, teaching practicum, and induction on a preservice science teacher. *Journal of Research in Science Teaching, 54*(6), 764–789. https://doi.org/10.1002/tea.21385

Lee, H. (2016). Conceptualization of an SSI-PCK framework for teaching socioscientific issues. *Journal of the Korean Association for Science Education, 36*(4), 539–550. https://doi.org/10.14697/jkase.2016.36.4.0539

Leung, J. S. C. (2021). Shifting the teaching beliefs of preservice science teachers about socioscientific issues in a teacher education course. *International Journal of Science and Mathematics Education*, 1–24. https://doi.org/10.1007/s10763-021-10177-y

Leung, J. S. C., Wong, K. L., & Chan, K. K. H. (2020). Pre-service secondary science teachers' beliefs about teaching socio-scientific issues. In M. Evagorou, J. A. Nielsen, & J. Dillon (Eds.), *Science teacher education for responsible citizenship* (pp. 21–39). https://doi.org/10.1007/978-3-030-40229-7_3

Levinson, R. (2013). Practice and theory of socio-scientific issues: An authentic model? *Studies in Science Education, 49*(1), 99–116. https://doi.org/10.1080/03057267.2012.746819

Levinson, R. (2018). Introducing socio-scientific inquiry-based learning (SSIBL). *School Science Review, 100*(371), 31–35.

Nielsen, J. A., Evagorou, M., & Dillon, J. (2020). New perspectives for addressing socioscientific issues in teacher education. In M. Evagorou, J. A. Nielsen, & J. Dillon (Eds.), *Science teacher education for responsible citizenship* (pp. 193–199). https://doi.org/10.1007/978-3-030-40229-7_12

Owen, R., Macnaghten, P., & Stilgoe, J. (2012). Responsible research and innovation: From science in society to science for society, with society. *Science and Public Policy, 39*(6), 751–760. https://doi.org/10.1093/scipol/scs093

Owens, D. C., Sadler, T. D., & Friedrichsen, P. (2019). Teaching practices for enactment of socioscientific issues instruction: An instrumental case study of an experienced biology teacher. *Research in Science Education, 51*, 375–398. https://doi.org/10.1007/s11165-018-9799-3

Phillips, M., Siebert-Evenstone, A., Kessler, A., Gasevic, D., & Shaffer, D. W. (2021). Professional decision making: Reframing teachers' work using epistemic frame theory. In A. R. Ruis & S. B. Lee (Eds.), *Advances in quantitative ethnography* (pp. 265–276). https://doi.org/10.1007/978-3-030-67788-6_18

Polanyi, M. (1966). *The tacit dimension*. Doubleday.

Presley, M. L., Sickel, A. J., Muslu, N., Merle-Johnson, D., Witzig, S. B., Izci, K., & Sadler, T. D. (2013). A framework for socio-scientific issues based education. *Science Educator, 22*(1), 26–32.

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching, 41*(5), 513–536. https://doi.org/10.1002/tea.20009

Sadler, T. D. (2011). Situating socioscientific ossues in classrooms as a means of achieving goals of science education. In T. D. Sadler (Ed.), *Socio-scientific issues in the classroom: Teaching, learning and research* (pp. 1–9). Springer. https://doi.org/10.1007/978-94-007-1159-4_1

Saunders, K., & Rennie, L. (2013). A pedagogical model for ethical inquiry into socioscientific issues in science. *Research in Science Education, 43*(1), 253–274. https://doi.org/10.1007/s11165-011-9248-z

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. Basic Books.

Shaffer, D. W. (2006a). Epistemic frames for epistemic games. *Computers & Education, 46*(3), 223–234. https://doi.org/10.1016/j.compedu.2005.11.003

Shaffer, D. W. (2006b). How computer games help children learn. *Palgrave Macmillan*. https://doi.org/10.1057/9780230601994

Shaffer, D. W., Hatfield, D., Svarovsky, G. N., Nash, P., Nulty, A., Bagley, E., Frank, K., Rupp, A. A., & Mislevy, R. (2009). Epistemic network analysis: A prototype for 21st-century assessment

of learning. *International Journal of Learning and Media, 1*(2), 33–53. https://doi.org/10.1162/ijlm.2009.0013

Simonneaux, L., & Simonneaux, J. (2008). Students' socio-scientific reasoning on controversies from the viewpoint of education for sustainable development. *Cultural Studies of Science Education, 4*(3), 657–687. https://doi.org/10.1007/s11422-008-9141-x

Tidemand, S., & Nielsen, J. A. (2017). The role of socioscientific issues in biology teaching: From the perspective of teachers. *International Journal of Science Education, 39*(1), 44–61. https://doi.org/10.1080/09500693.2016.1264644

Topçu, M. S., Foulk, J. A., Sadler, T. D., Pitiporntapin, S., & Atabey, N. (2018). The classroom observation protocol for socioscientific issue-based instruction: Development and implementation of a new research tool. *Research in Science & Technological Education, 36*(3), 302–323. https://doi.org/10.1080/02635143.2017.1399353

Zeidler, D. L. (2014). Socioscientific issues as a curriculum emphasis: Theory, research, and practice. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. 12, pp. 697–726). Routledge Press.

Zeidler, D. L., Herman, B. C., & Sadler, T. D. (2019). New directions in socioscientific issues research. *Disciplinary and Interdisciplinary Science Education Research, 1*(1), 1–11. https://doi.org/10.1186/s43031-019-0008-7

Zhang, W.-X., & Hsu, Y.-S. (2021). The interplay of students' regulation learning and their collective decision-making performance in a SSI context. *International Journal of Science Education, 43*(11), 1746–1788. https://doi.org/10.1080/09500693.2021.1933250

Wen-Xin Zhang is a post-doctoral research fellow in the Graduate Institute of Science Education at National Taiwan Normal University (NTNU), Taiwan. She has researched students' higher-order thinking and learning, including students' inquiry ability and metacognition in the inquiry practice, collaborative regulation behavior in groups, informal reasoning, and decision making ability in the SSI context. She gained her PhD at NTNU, where she focused on students' metacognition and its effects on students' inquiry learning in the inquiry practice.

Ying-Shao Hsu is a Professor of Graduate Institute of Science Education and the Department of Earth Sciences; currently, she is Chair Professor of NTNU. She received her PhD degree in 1997 from the Department of Curriculum and Instruction at Iowa State University. Her research focuses on inquiry learning, e-learning and teaching, metacognition, social-scientific issue education, and STEM education. Professor Hsu's research work has been recognized with Outstanding Research Awards by the Minister of Science Technology (MOST) in Taiwan (2011 and 2015) and Wu Da-Yu Memorial Award (2005).