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Science teachers' pedagogical content knowledge development during enactment of socioscientific curriculum materials

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Abstract

The purpose of this study is to provide insight into short-term professionalization of teachers regarding teaching socioscientific issues (SSI). The study aimed to capture the development of science teachers' pedagogical content knowledge (PCK) for SSI teaching by enacting specially designed SSI curriculum materials. The study also explores indicators of stronger and weaker development of PCK for SSI teaching. Thirty teachers from four countries (Cyprus, Israel, Norway, and Spain) used one module (30–60 min lesson) of SSI materials. The data were collected through: (a) lesson preparation form (PCK-before), (b) lesson reflection form (PCK-after), (c) lesson observation table (PCK-in-action). The data analysis was based on the PCK model of Magnusson, Krajcik, and Borko (1999). Strong development of PCK for SSI teaching includes "Strong interconnections between the PCK components," "Understanding of students' difficulties in SSI learning," "Suggesting appropriate instructional strategies," and "Focusing equally on science content and SSI skills." Our findings point to the importance of these aspects of PCK development for SSI teaching. We argue that when professional development programs and curriculum materials focus

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on developing these aspects, they will contribute to strong PCK development for SSI teaching. The findings regarding the development in the components of PCK for SSI provide compelling evidence that science teachers can develop aspects of their PCK for SSI with the use of a single module. Most of the teachers developed their knowledge about *students' understanding of science* and *instructional strategies.* The recognition of student difficulties made the teacher consider specific teaching strategies which are in line with the learning objectives. There is an evident link between the development of PCK in *instructional strategies* and *students' understanding of science* for SSI teaching.

KEYWORDS

pedagogical content knowledge, socioscientific curriculum materials, socioscientific issues

1 | INTRODUCTION

To educate future citizens who are familiar with the scientific way of thinking, and can use this insight in everyday life, many countries have incorporated socioscientific issues (SSI) in science curricula. Moreover, scientific competency goals in the curriculum of most countries require that science teachers should help students to acquire certain skills (e.g., discourse, argumentation, decision making, and assessing the validity of sources of information) to become responsible citizens (Bybee, 2014; European Commission, 2015). There is evidence that teaching SSI fosters students' learning of the aforementioned skills, knowledge of science, and motivation for science learning (Simonneaux & Simonneaux, 2009a; Zeidler, Sadler, Simmons, & Howes, 2005).

However, according to research in SSI teachers find using SSI in their teaching practice challenging (e.g., Han-Tosunoglu & Irez, 2017; Lee, Abd-El-Khalick, & Choi, 2006; Pitiporntapin, Yutakom, & Sadler, 2016; Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006; Simonneaux, 2014). In particular, teachers are reluctant to use SSI approaches due to concerns about their own abilities (Pitpiorntapin & Topcu, 2016; Saunders & Rennie, 2013; Simonneaux, 2014; Tidemand & Nielsen, 2017), their naive understanding of science (Day & Bryce, 2011; Kilinc, Demiral, & Kartal, 2017), time constraints linked to the curriculum (Levinson & Turner, 2001; Tidemand & Nielsen, 2017), lack of understanding of assessment of the competencies included in SSI teaching (Levinson & Turner, 2001; Tidemand & Nielsen, 2017), and lack of supporting materials and tools (Ekborg, Ottander, Silfver, & Simon, 2013; Sadler, Foulk, & Friedrichsen, 2017; Saunders & Rennie, 2013).

One way to help teachers to overcome this challenge is to give them access to SSI curriculum materials. Literature shows that curriculum materials improve the quality of instruction (Beyer & Davis, 2012; Squire, MaKinster, Barnett, Luehmann, & Barab, 2003), and support the implementation of new ways of teaching, and new instructional strategies (IS; Schneider & Krajick, 2002). On the other hand, choosing and using appropriate curriculum materials is not a guarantee for effective teaching. Teachers should help their students to use scientific knowledge and make informed decisions on SSI by thinking scientifically and using higher order thinking skills (Sadler, 2011). To do this, teachers should develop pedagogical knowledge of SSI.

As highlighted by Tidemand and Nielsen (2017), teacher research on SSI is still an emerging field. The majority of studies focus on the implementation of specially designed long-term professional development (PD) programs and their impact (Dawson & Venville, 2011; Saunders & Rennie, 2013), or on teachers co-designing and implementing interventions with researchers (Bencze & Krstovic, 2017; Friedrichsen, Sadler, Graham, & Brown, 2016). However, there are limited studies on how teachers, who did not receive any scaffolding, develop their understanding and knowledge of SSI teaching, especially without participating in long-term PD (Tidemand & Nielsen, 2017). In other words, little is known about what happens to teacher knowledge, specifically pedagogical content knowledge (PCK), during SSI instruction (Bayram-Jacobs et al., 2017; Han-Tosunoglu & Irez, 2017; Han-Tosunoglu & Lederman, 2016).

It is widely accepted that teacher knowledge is an indicator of the quality of instruction and teacher behavior in the classroom (e.g., Barendsen & Henze, 2017; Clark & Peterson, 1986; Verloop, Van Driel, & Meijer, 2001). Given that PCK is accepted as an essential knowledge base for teaching (Shulman, 1986), it is important to investigate how teachers' PCK develops while teaching SSI.

Based on the gap as mentioned above, the current study aims to explore how science teachers' PCK develops while implementing specially designed curriculum materials, and the possible explanations in terms of teacher characteristics associated with this development.

We chose to use specially designed curriculum materials instead of a long-term PD based on the following: (a) long-term PD courses might not be available to all teachers depending on the circumstances of their professional practice (incentives for PD, during or out of school time), and (b) teachers state that there is a lack of SSI materials, which makes it difficult for them to teach SSI (Levinson & Turner, 2001).

The importance of the current study lies on that: (a) there are limited studies exploring how teachers' knowledge to teach SSI develops (Tidemand & Nielsen, 2017), especially through the lens of PCK (Han-Tosunoglu & Irez, 2017; Han-Tosunoglu & Lederman, 2016), and (b) our study explores how in-service teachers develop their PCK to teach SSI through the implementation of specially designed curriculum materials, without engaging in long-term PD.

2 | CONCEPTUAL FRAMEWORK

2.1 | Development of teacher PCK for SSI teaching

Socioscietific issues are defined as ill-defined problems that are conceptually connected to science (Sadler, 2004). We view SSI as controversial problems that a significant number of people would argue about, without necessarily reaching a conclusion or consent (Oulton, Dillon, & Grace, 2004; Zeidler & Sadler, 2008). Thus, these issues are different from other topics usually presented in a science classroom, especially regarding the uncertainty that they bring with them (Sadler & Zeidler, 2004). In this regard, we understand SSI teaching as an educational reform.

To help students to integrate science knowledge with SSI for evidence-based thinking and reasoning in a given context, teachers must develop pedagogical know-how and practice, such as PCK. It is believed that PCK is a necessary body of knowledge for science teachers to apply educational reform. Our rationale is that teachers with strong PCK for SSI teaching are more likely to implement this approach in classroom practice than others (Henze, van Driel, & Verloop, 2007; Park, Jang, Chen, & Jung, 2011).

In this study to capture PCK development, we used four PCK components from the PCK model of Magnusson, Krajcik, and Borko (1999). Magnusson and colleagues reconceptualized the models of Tamir (1988) and Grossman (1990) who followed and re-examined Shulman's (1986, 1987) ideas about a knowledge base for teaching science. We chose this model, because the PCK components that are suggested in this model are presented in many pedagogical models (i.e., Putnam, 1987) so, it offers a thorough examination of teacher knowledge. The four components that we used are: (a) Knowledge of Goals and Objectives (GO), (b) Knowledge of Students' Understanding of Science (SU), (c) Knowledge of Instructional Strategies (IS), and (d) Knowledge of ways to assess students' understanding (AS). The first component (GO) refers to teacher knowledge on the goals and objectives of the subject they teach, and the knowledge about the vertical curriculum (what students previously have learned); the second component (SU) includes teacher knowledge about requirements from students to learn a specific subject (skills, pre-knowledge, and abilities), and expected student difficulties for learning a particular subject; the IS component addresses subject-specific and topic-specific strategies to teach science content; and the AS component covers knowledge of dimensions of learning to assess and knowledge of assessment methods.

2.1.1 | Interconnection between PCK components

In this study, we examined teacher PCK for SSI teaching through exploring the development in the four separate PCK components, and the interconnection between them. Although Magnusson et al. (1999) do not mention the interconnection between the PCK components, following Barendsen and Henze (2017), and Park and Chen (2012) we believe that both the richness of the respective PCK components and their interconnectedness (as a measure of coherence in teachers' pedagogical reasoning) indicate the strength of teacher PCK and therefore its transference to classroom practice.

That is, for example, when a teacher plans to use different instructional strategies by considering his/her students' understanding of science (including their difficulties; Alonzo & Kim, 2016) and plans to assess learning through appropriate ways/tools and all of these are in line with the goals of the lesson, this teacher has strong PCK. Moreover, a teacher with strong PCK can provide solid support to students throughout their learning process (Hashweh, 2005; Loughran, Berry, & Mulhall, 2012; Mthethwa-Kunene, Onwu, & de Villiers, 2015). This is the reason why in this study, we not only explore the development in the separate PCK components but also in the interconnection between the PCK components. The interconnectedness of PCK components is displayed in Figure 1.

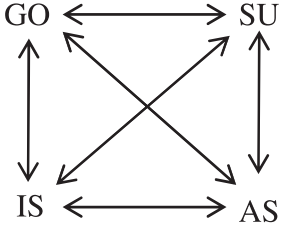

FIGURE 1 PCK components and their interconnections (Adapted from Barendsen & Henze, 2017)
Abbreviation: PCK, pedagogical content knowledge

2.1.2 | PCK for SSI teaching

Shulman (2015) defined PCK as domain-specific teacher knowledge. He also argues that "domain" can refer to a discipline, a subject-matter, a specific problem, a topic, and so on. Similarly, Schneider (2013), from a teacher educator's point of view, mentions that we need to understand PCK as domain-specific to support teachers' professional development. In this study, we follow Shulman's point of view on PCK as domain-specific teacher knowledge where we understand SSI as a domain, and we aim to investigate the development of PCK during the practice of SSI materials.

We grounded a framework of interpretation for PCK in the domain of SSI which is presented in detail in the Section 6 (Table 2). Putting Magnusson et al.'s (1999) PCK model to the SSI domain, acquainted us with indicators of each PCK component. That is, for example "applying scientific knowledge to solving a societal issue" informs about the GO PCK component, "using scientific knowledge in arguments" informs about the SU component, "discussion (whole class or small group)" is an example of the IS component, and "student self-assessment" is an illustration of the AS PCK component.

In the following section, we present background information to provide a better understanding of the above-mentioned concepts.

3 | BACKGROUND

Despite the expanding body of research that has documented how SSI is associated with educational goals, there are fewer advances in how teachers incorporate SSI (Sadler et al., 2017; Tidemand & Nielsen, 2017). Studies in this area emphasize teachers' beliefs and understanding about the role of SSI in science teaching (Ekborg et al., 2013; Tidemand & Nielsen, 2017); teachers' reported difficulties in engaging with SSI (Levinson, 2006; Pitiporntapin et al., 2016; Pitpiorntapin & Topcu, 2016; Sadler et al., 2017; Saunders & Rennie, 2013); teachers' lack of awareness of the promises of SSI teaching (Lazarowitz & Bloch, 2005); and teachers' change in practice when engaging in teacher PD or co-design of SSI activities (Bencze & Krstovic, 2017; Dawson & Venville, 2011; Friedrichsen et al., 2016; Saunders & Rennie, 2013).

As a result of critically reviewing previous studies, it becomes clear that teachers face the following difficulties in implementing SSI: (a) working with SSI is a different skill and pedagogy, and requires teachers to organize classroom work differently, often introducing practices like argumentation and value-laden discussions that are unfamiliar to them (Ekborg et al., 2013); (b) even when teachers are willing to introduce SSI in their classes the way in which they perceive science education—as aiming to deliver content or facts, and being value-free—impedes their efforts (Levinson & Turner, 2001; Saunders & Rennie, 2013); (c) a large number of teachers tend to focus on content rather than on the competences and values when teaching SSI, mostly because of their own personal interest in the topic or because they feel uncomfortable discussing ethical issues for which they do not have the answer (Tidemand & Nielsen, 2017); (d) they emphasize on factual knowledge in their assessment or are uncertain about how to assess SSI learning (Tidemand & Nielsen, 2017); (e) teaching SSI puts demands on them to use information and knowledge from outside their scientific domains (i.e., moral, financial, ethical dilemmas; Simonneaux & Simonneaux, 2009b), and be well-informed about SSI in the news (Yakob, Yunus, & May, 2015). All these difficulties (what teachers *do*) can be explained with PCK (what teachers *know*) because they ask for knowledge lying in the intersection between teaching the new curriculum, in a particular way, to a particular group of students.

PD in SSI is usually long term and emphasizes presenting pedagogical strategies that can address teachers' aforementioned difficulties. For example, Saunders and Rennie (2013) have proposed a framework to teach SSI which incorporates ethical thinking, and they engaged a small number of teachers in two workshops. Most of the teachers reported knowing very little about SSI and ethical thinking before the workshop. The teachers reported unexpected learning and talked especially about the excitement and motivation of their students. The use of the specific model in training helped the teachers to develop a stronger pedagogical base to support their teaching and learning about SSI and using the model the teachers' knowledge about ethical frameworks increased. Other examples of long-term PD include teachers and researchers working together to co-design SSI activities (e.g., Friedrichsen et al., 2016) which again has led to teachers' becoming comfortable in implementing SSI in their classes.

According to Ekborg et al. (2013) and Aikenhead (2006), most of the studies focus on long-term PD with teachers who are specially selected, and not with teachers from everyday classrooms. Besides, Han-Tosunoglu and Lederman (2016) point out that previous work in socioscientific research has not focused on PCK for SSI and very few studies have examined teachers' understanding of SSI and competencies to teach SSI through the view of PCK. Furthermore, there seems to be a lack of resources for implementing SSI, and lack of appropriate teaching material (e.g., Sadler et al., 2017; Saunders & Rennie, 2013).

PCK is defined as a teacher knowledge that plays a crucial role in transferring content knowledge into teaching practice (Kulgemeyer & Riese, 2018). When teachers apply their knowledge to classroom practice, they engage in complex reasoning processes, for example, selectively retrieving knowledge they think is most relevant and using that knowledge in flexible ways to address a particular situation. Using their PCK in practice, teachers can also combine their knowledge in new ways, resulting in the development of new PCK (Beyer & Davis, 2012).

There is a vast body of research that proves the impact of curriculum materials on teacher learning, and practice. Undoubtedly, the materials have a crucial role in scaffolding teachers' learning and classroom practice through the stages of planning, enacting, and reflecting on a lesson (Ball & Cohen, 1996; Davis & Krajcik, 2005; Remillard, 2000; Schneider, Krajcik, & Blumenfeld, 2005; Schneider & Krajick, 2002). The materials support not only teaching specific content but also teachers' PD during the enactment of a lesson (Davis & Krajcik, 2005). Teachers' interactions with curriculum materials are mediated by their knowledge and beliefs about the subject matter, teaching, and learning (Beyer & Davis, 2012: Brown, 2009; Collopy, 2003; Pintó, 2005; Squire et al., 2003).

Therefore, as well as PD courses the curriculum materials are often used for PD purposes. In particular, for incorporating reform-based approaches the materials are used in scaffolding teachers (Ball & Cohen, 1996). Moreover, research suggests that teachers develop PCK while using curricular materials in the context of curricular reform (Beyer & Davis, 2012; Beyer, Delgado, Davis, & Krajcik, 2009). Teachers based their teaching on curriculum materials especially when they need to move out of their comfort zone and have to apply new pedagogies (Beyer et al., 2009). Supporting teachers' immediate needs the materials directly influence the daily practice of teachers (Grossman & Thompson, 2008). On the contrary, after completing PD programs, coaching and mentoring are needed to impact the daily instruction of teachers. Thus, curriculum materials are suggested as useful means for changing traditional ways of teaching science (Beyer et al., 2009).

Teacher engagement in the materials fosters growth not only in PCK, but also in pedagogical knowledge, and teaching style (Beyer et al., 2009; Gess-Newsome, Carlson, Gardner, & Taylor, 2010; Schneider & Krajick, 2002). Research proves the positive effect of curriculum materials on teachers' knowledge, especially regarding diverse IS and pedagogical approaches (Ball & Cohen, 1996; Beyer et al., 2009; Davis & Krajcik, 2005; Schneider et al., 2005). While using new materials teachers improve their understanding of how specific content can be taught, what are the challenges, the expected difficulties or misunderstandings, and how to organize the lesson to cater for different interests, background, and motivation of their students (Davis & Krajcik, 2005; Shulman, 1987). It was also reported that teachers who implemented curriculum materials adapted the content and used different strategies during their instruction (Cervetti, Kulikowich, & Bravo, 2015). Likewise, the materials supported teachers to notice students' ideas about science (Beyer & Davis, 2009).

4 | CONTEXT OF THE STUDY

In this study, the teachers enacted SSI materials that were developed as part of a European Commission project ENGAGE which was granted under the "science in society" call. The ENGAGE project claims that the traditional ways of teaching science should be changed to engage the young generation in SSI. For this purpose, the project team developed science-in-the-news, socioscientific curriculum materials to foster the engagement of European teachers and students in SSI. The materials are ready-to-use, open educational resources, and each module includes a teacher guide, student worksheets, and presentation materials. Designed materials are aligned with SSI theoretical and practical foci regarding the nature of context, role of teacher and students, practices (discourse, argumentation, and critical thinking) and the integration of science content (Zeidler & Nichols, 2009).

The project materials are available in nine different languages and are also adapted to the local context and curriculum for each of the 12 participant countries.

4.1 | The materials and SSI

The materials aim to support the students in developing knowledge, skills, and attitudes to deal with SSI in their lives and to develop informed opinions on emerging science and technology. Specifically, the materials aim to make students:

- become aware of the relation between science and society: This is part of what is known as Knowledge about Nature of Science or Ideas about Science, which is quoted as one of the purposes of SSI-based instruction (Lundström, Sjöström, & Hasslöf, 2017; Sadler, Barab, & Scott, 2007; Zeidler et al., 2005)
- be able to question and evaluate the evidence for a scientific claim, and analyze an issue and possible actions, by applying scientific knowledge and developing a reasoned opinion or decision: This has been used in STS approaches, which are precursors to SSI (Pedretti & Nazir, 2011).
- be able to construct an argument to express an opinion using knowledge of scientific big ideas, or critique another's argument.

A framework to design materials was developed by combining scientific ideas with SSI goals and practices, strategies, and specific outcomes. The design principles of the materials include: curriculum match, a topic that invites controversial discourse, inquiry-based teaching, the tentativeness of science, engaging students in science lessons, and promoting teacher learning (Bayram-Jacobs, 2016; Shwartz & Sherborne, 2015). Moreover, the 5E learning cycle (Bybee, Carlson-Powell, & Trowbridge, 2008) was used as an instructional model in the design of the materials. This learning cycle puts students in the center, engages them in science learning, and fosters them in their learning process.

All materials include activities which follow a similar structure: Presenting a dilemma, recap, or learn scientific knowledge needed for the task, and a students' SSI task which is a simple, structured activity to resolve the dilemma. For example, the material "Three Parents" introduces the dilemma

"Babies will soon be born which have two Mums and a Dad. Do you think it should be allowed?" Moreover, the material makes students use knowledge about genes to explain how to create an embryo with three parents. The SSI skill that the materials aim to develop is "to make a decision about a new technology using ethical thinking." It includes three student activities: (a) find out about *Leber's hereditary optic neuropathy* (*LHON*) disease (how it affects cells, what causes it, how it is passed on), (b) find out about the *3 parent technology* (how it is carried out, how it can help women with LHON to have a healthy baby), (c) write a summary for your friends (decide whether you think the technique could help them and explain how).

5 | THE STUDY: AIMS, HYPOTHESES, AND RESEARCH QUESTIONS

As elaborated in the previous sections, stronger PCK could help teachers to overcome the difficulties in using SSI in science lessons. It is also known that teachers' learning, their knowledge integration, and ideas about certain aspects of teaching are supported using curriculum materials (Schneider, 2013; Schneider & Krajick, 2002). Teachers often need to adapt and differentiate the materials according to level, interest, skills, and previous knowledge of their students. Both during adaptation and enactment of the materials, teacher knowledge grows, changes, and is connected with other types of knowledge (Clarke & Hollingsworth, 2002; Davis & Krajcik, 2005; Schneider & Krajick, 2002; Van Driel & Henze, 2012). Therefore, our research hypothesis is that teacher PCK for SSI develops and becomes stronger by teaching specially designed socioscientific curriculum materials.

5.1 | Research goals

This study aims to capture science teachers' PCK development during the enactment of SSI curriculum materials. More specifically, we are interested in exploring the development that takes place in teachers' PCK for SSI with the implementation of one SSI module (designed to be enacted in a 30–60 minute lesson, some teachers spent longer time in more than one lessons). We aim to obtain a deeper understanding of the quality of PCK for SSI by characterizing indicators for weaker and stronger development of PCK for SSI. For this purpose, the study addresses the following question:

How did the teachers' PCK for SSI develop by enacting specially designed socioscientific materials?

1. Which PCK components developed?
2. To what extent are the components of PCK for SSI interconnected before, and after the lesson?

The answers to these questions help to establish a relation between curriculum materials and PCK for SSI teaching, even after a single use of the materials (in 30–60 min lesson). It could eventually enable us to formulate grounded recommendations on how to inform teacher PD in the area of PCK when teaching the social dimension of science and socioscientific practices in daily life. We believe that this is the first study that shows the development of teachers' PCK for SSI teaching after using one module of socioscientific materials.

The findings of this study might provide insights into the short-term professionalization of teachers in addition to other ways of teacher PD and scaffolding teachers' PCK development for SSI teaching by SSI curriculum materials.

6 | METHOD

6.1 | Research design

This qualitative research started with a pilot study, which aimed to develop, test, refine the data collection strategies and the instruments, and to prepare the initial coding list as well as data analysis procedure for the present study. The instruments provided useful data to find out patterns in the PCK development of the teachers who used one module of the SSI materials (Bayram-Jacobs & Henze, 2016). After the pilot, the main qualitative study which included an international team of eight researchers, working at different locations (Cyprus, Israel, Norway, Spain, and the Netherlands) took place. The team was led by two senior researchers (authors 1 and 2). In the research procedure, relevant aspects of the literature on translational discourses (e.g., Nerland, 2010) were included.

The *trustworthiness* (Guba & Lincoln, 1981) of this qualitative study was ensured by keeping the following quality components: "methodological coherence," "appropriate sample," "collecting and analysing data concurrently," "thinking theoretically," and "deliberating between microdata perspective and a macro-theoretical understanding" (Morse, Barnett, Mayan, Olson, & Spiers, 2002). For this purpose, we applied regular debriefing in the research team, routine face to face and online meetings, trial exercises for data collection and analysis, systematic checks, and discussions.

6.2 | Participant teachers and teacher recruitment

A total of 30 teachers from four countries (Cyprus, Israel, Norway, and Spain) participated in the study, who were not influenced by any other ENGAGE interventions (i.e., ENGAGE teacher workshops or online courses). From the pilot study, it was concluded that a minimum number of seven teachers per country is adequate to reach data saturation (Mason, 2010). There were nine teachers from Israel and seven teachers from each of the other three countries, which were recruited using convenience sampling (Etikan, Musa, & Alkassim, 2016; Marshall, 1996). Teachers participated in this study on a voluntary basis. They chose and enacted one module of SSI materials in a single lesson (30–60 minutes) for introducing an SSI in their science classroom. They used the complete module (presentation, teacher guide, and student sheets) of the materials without any previous training.

6.3 | Data collection process and sources

We used the PCK model by Magnusson et al. (1999) where we gathered data through three forms that are given in Supporting Information. To capture teachers' PCK before and after using the materials, the *Lesson Preparation* and *Lesson Reflection* forms were used (Figure 2). These two forms are based on the Content Representation instrument (Loughran, Mulhall, & Berry, 2004) and the PCK model by Magnusson et al. (1999). To observe the teachers' manifestations of PCK in their classrooms an *Observation Table* which was developed by Barendsen and Henze (2015) was used. These instruments were previously validated in various studies (Barendsen & Henze, 2017; Bayram-Jacobs & Henze, 2016; Henze & Barendsen, 2019).

The instruments were translated by each researcher into their language. During the period of translation, several online meetings were arranged to keep content validity, that is, the meaning of the expressions. To ensure that the instruments are natural and perform in the same way in each language, back translation was performed (McGorry, 2000).

The initial research plan including the participant teachers' profile and instructions to use the data collection instruments were prepared by the leading researchers, and then discussed and refined by the whole research team. Furthermore, several instructional videos were prepared about using the instruments, coding and analysing the data. Several online and face-to-face meetings were held to document and achieve consensus on the procedures for data collection and analysis.

6.3.1 | Lesson preparation form

The lesson preparation (LP) form has two parts. The first part includes questions to collect data about the demographics of the teachers. The second part contains the topic and context-specific questions. There are questions about the class, student age, subject of the lesson, goals and learning objectives, potential student difficulties, prior knowledge of students, other factors affecting the learning process, teaching approach, and assessment ways. We also asked the teachers whether they want to adapt/edit the material to make it relevant to their students.

The teachers completed the form before the enactment of the lesson and provided to the national research team.

6.3.2 | Lesson reflection form

The lesson reflection (LR) form has also two parts where the first part is the same as that of the LP form. The second part contains questions about the goals of the lesson, learning objectives, to what extent the learning goals reached, any alternative knowledge or misconception of students, any student difficulty faced, any variation from the original lesson plan, how successful were the activities, engagement of students, and extent of the match of the activities and the lesson goals. There were also questions regarding any future adaptation/modification ideas for the material.

The teachers completed the LR form after enacting the chosen SSI material in their classroom. For both forms (LR and LP) to use the forms in the same way, the guide that includes instructions to use the forms and explanations of each question supported the researchers and the teachers in this process.

6.3.3 | Lesson observation table

The lesson observation (LO) table was used to observe the teachers' classroom practice which is a manifestation of their PCK in practice. “Lesson content,” “Instructional method,” and “Assessment” are the categories of the LO table. The LO table was divided into intervals of 3 minutes to understand how long certain activity or action took place and where the focus of the teacher and the lesson was. Therefore, using the LO table, we performed structured observation. Most of the observation data (all lessons from Israel and Cyprus and three lessons from Norway) were collected by observing

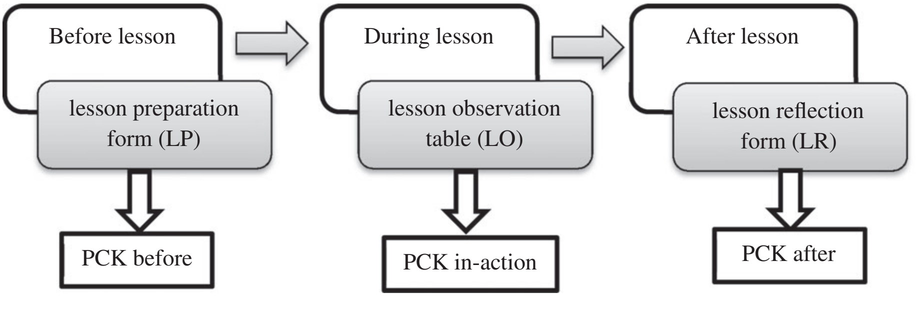

FIGURE 2 Research design

the lessons directly. The observation data of all of Spanish and four Norwegian classes were not gathered by direct observation but from the video recordings of the lessons. To ensure consistency, "an observation guide" was prepared. The LO table was piloted by all the researchers through coding the video of one particular science lesson. The researchers sent the completed LO table to the first author to check the interrater reliability. We used the data from the observation table for verification purpose (Morse et al., 2002) so, to confirm the investigations from the other two data sources.

6.4 | Data analysis process

The coding process was not linear but iterative where the code list, new codes, and coding strategy were checked, refined, and confirmed. First, an a-priori code list was elaborated as a result of a pilot study and based on the four components of PCK. We used the four PCK components from the model of Magnusson et al. (1999) as broad categories of the codes (GO, SU, IS, and AS) and from the same model we identified the initial codes under these four categories (e.g., GO-personal objectives, GO-learning objectives, SU-student difficulties, and SU-misconceptions or beliefs; Table 1). The data analysis was started reading the data thoroughly without applying any codes to develop an understanding of the whole data. In the coding process, a combined approach of analytic coding (Gibbs, 2007), open and axial coding (Cohen, Manion, & Morrison, 2000) was used. The data were coded using Atlas.ti qualitative data analysis software. First, we performed a coding exercise where the researchers coded the data (lesson preparation and lesson reflection forms) from the same teacher. The interrater agreement was 89% (Miles & Huberman, 1994). After the coding exercise, the a-priori code list was updated with new codes that appeared to be significant and frequently emerged from the data.

In the first cycle of the coding, the researchers coded the data to capture the PCK development using the same code list that is presented in Table 1. With the term PCK development, we refer to the positive changes in PCK regarding teaching SSI after the implementation of the lesson, as these were captured by comparing the analysis of the lesson preparation and lesson reflection forms. When the PCK components were richer, extended, and more corresponding to SSI teaching, and a teacher's reasoning was coherent among the PCK components, we called these positive changes "PCK development." In this round, we coded the data deductively by using the codes from the first four categories (GO, SU, IS, and AS) of the code list (Table 1). For example, when a teacher mentioned "I want to motivate them [students] to study science subjects" we coded it as "personal objectives," and when a teacher stated the objective as "I want students to know about the particles model" we applied "science content objectives" code. We analyzed the data by focusing on the quality of the teachers' reflection about SSI teaching. The data demonstrating development in a component of PCK that is not related to teaching SSI were not coded. At the end of this cycle, we investigated the development in the teachers' PCK components for teaching SSI (as an answer for subquestion 1).

In the second cycle of coding, as given in the Section 3, the interconnections between the PCK components were used to identify the quality of PCK for SSI. For this purpose, the codes from the category "CON" (deductive codes, Table 1) were used to explore the interconnections between the PCK components, for example, if there is interconnection between the students' understanding (e.g., student difficulties, knowledge and skills, and misconceptions or beliefs) and the IS (e.g., teaching approach, adapting the activities, and activities used) we applied the code "Interconnection: SU & IS". When an interconnection was investigated, we coded its nature with the codes (deductive and inductive codes) from the category "NoC" (Table 1), for example, interconnection regarding "science content," or "student difficulties in SSI skills."

TABLE 1 Coding scheme for PCK

Categories	Codes
Goals (GO)	*Personal objectives* • Contact with students, motivate students • Promoting scientific literacy, engage in scientific concepts • Applying scientific knowledge to decision-making/solving a societal issue • Guiding social–emotional and moral development • Motivating nonmotivated/noninterested students • Show connections between science and real life • Teaching students to think critically • Educating responsible citizens *Learning objectives* • Science content (e.g., particles model, evolution of stars, development of planets, sources of energy, atmospheric pollution, combustion and emission, etc.) • Skills (e.g., physical/motoric skills, communication, reflection, argumentation, critical thinking, making decisions) *Importance for the students* • Exam/curriculum • Future • Critical thinking • Combining science knowledge with daily life *Reason choosing the material* • Fits with the curriculum • Fits with the students' interest/personal life • Social relevance • Personal interest of teacher
Student understanding (SU)	*Student difficulties with*: • Science concepts • Prior knowledge • SSI skills (e.g., communication, reflection, argumentation, using scientific knowledge in their arguments, discussion, making decisions, collaboration, inquiry, working autonomously) *Misconceptions or beliefs* • Students' misconceptions or beliefs on the topic • Students' alternative ideas
Instructional strategies (IS)	*Teaching approach* • For example, making changes to the lesson, adding concepts, skipping activities, etc. *Adapting the activities* • For example, extra content, emphasis on social aspects, link to personal life, adding instructional video *Teaching activities used* • Group work, whole class discussion, discussion in small groups, debate, argumentation *Difficulties teacher faced* • In teaching activity (argumentation, discussion) • In content *Time management* *Further adaptation ideas* • Grouping students differently • Using different teaching strategy

(Continues)

TABLE 1 (Continued)

Categories	Codes
Assessment (AS)	*Ideas about what is a successful lesson* • For example, fun for students, students are interested, goals are fulfilled *Ways of assessment used* • Observing students • Following discussion • Assessing student learning products: student report, essay, video, presentation, personal reflection • Peer assessment: Students assess each other's products *Further ideas for assessment* • Formulating learning objectives in a measurable way
Interconnection between PCK components (CON)	Connection: SU & IS & AS Connection: SU & IS & GO Connection: SU & IS Connection: GO & IS Connection: GO & SU Connection: GO & AS
Nature of interconnection between PCK components (NoC)	*Interconnection regarding*: • Science content • Students' difficulties in SSI skills (argumentation, discussion, using science knowledge to solve a societal problem) • Teachers' own difficulties in SSI teaching (guiding discussion and dilemma, scaffolding students) • Lesson design (time, clear objective, teaching strategies for SSI teaching, measurable objectives) • Aspects of SSI (moral and ethical, social, scientific, political)

Abbreviations: PCK, pedagogical content knowledge; SSI, socioscientific issues.

Following this round, to diagnose the nature of the development in the teachers' PCK for SSI and to make sense of the data, we prepared a table per country for all teachers (in total four tables). These tables included responses of the teachers organized according to four PCK components before and after the lesson, a teacher's characteristics (teaching experience and education background), SSI materials used, and the students' age. In addition, all researchers wrote memos for their teachers (totally 30 memos) describing each teacher's PCK before and after the lesson including some illustrative quotations. Both, the tables and the memos supported us in the interpretation process for understanding the nature of the interconnections between the PCK components and characterizing PCK for SSI teaching (as an answer for subquestion 2).

In the third round, we revisited the coded segments for "interconnection of the PCK components" and "the nature of interconnection" to search for sense-making and interpretation of the patterns in the quality of PCK for SSI. For this purpose, the three-step formula (describe, compare, and relate) was used (Bazeley, 2009). In this inductive process, we explored relations among the first four (GO, SU, IS, AS), and the fifth (CON) and sixth (NoC) categories. Checking the connections and forming a link between the categories helped us to identify three quality groups (strong, intermediate, and weak) of PCK development for SSI teaching. Afterwards, we looked for confirmation and possible exceptions in the data to confirm the groups that we identified. To identify the indicators for strong, intermediate, and weak PCK development for SSI we re-read the coded segments and the memos of each group of teachers by checking whether a teacher's pedagogical reasoning was coherent among the interconnected PCK components for SSI teaching. This inductive approach (Thomas, 2003) lead us to illuminate the most significant indicators for strong, intermediate, and weak PCK development for SSI teaching.

7 | RESULTS

In this section, we first present the results for the development in the components of PCK for SSI teaching (first sub-question) and then, the results for the interconnection between the components of PCK for SSI where we explored the quality of PCK for SSI (second sub-question).

7.1 | Development in the components of PCK for SSI

The analysis of the development of the PCK components reveals that most teachers' PCK development was captured in the knowledge of *students' understanding of science* (18 teachers), and *instructional strategies* (17 teachers). There was some development in the *knowledge of learning goals* (12 teachers) and only slight growth in the *ways to assess students' understanding* (3 teachers; see Table 2).

Hence, by teaching the SSI materials the teachers mostly developed understanding about their students' learning and areas of students' difficulty, especially the students' differing needs included: prior knowledge on the subject, different learning styles, difficulty in chemistry concepts, difficulties with SSI skills (e.g., communication, argumentation), misconceptions, and knowledge of the real world. Moreover, the teachers developed their knowledge of IS for teaching SSI. For example, using strategies such as argumentation, discussion (including ethical and religious aspects), and group work, and using pedagogical tools like an argumentation tool, a decision-making tool, and constructing explanations tools.

Additionally, the teachers developed their knowledge about goals and objectives. They mentioned setting more realistic goals, for example, less number of goals, which they can achieve in one lesson. Moreover, their goals in the post-reflection were more related to SSI for example, goals about critical thinking, uncertainty, nature of science, making informed decisions, applying science knowledge to

TABLE 2 Development in teachers' PCK for SSI

PCK development	PCK component(s)	Number of teachers	Total
3 PCK components	GO & SU & IS	3	4
	SU & IS & AS	1	
2 PCK component	IS & SU	8	17
	GO & SU	5	
	GO & IS	4	
1 PCK component	IS	1	4
	AS	2	
	SU	1	
No change		5	5
Total		30	30

Abbreviations: PCK, pedagogical content knowledge; SSI, socioscientific issues.

solve a societal problem, and educating responsible citizens. They also improved their understanding of the students' levels, especially while choosing skills related goals. The least development appeared in the knowledge of the assessment component of PCK.

7.2 | Interconnection between the components of PCK for SSI

We examined the richness and interconnectedness of the PCK components that were developed, and the nature of the interconnections. In this way, we characterized the quality of the teachers' development of PCK for SSI teaching into three groups: strong, intermediate, and weak.

7.2.1 | Strong development in PCK for SSI

Strong development of PCK for SSI includes *strong interconnections* between the three PCK components after the lesson, which were mostly found between GO, SU, and IS components of a teacher's PCK. That means the teacher's reasoning among the PCK components was coherent. In all cases, the lesson helped the teachers to understand better students' difficulties (SU) and ways to scaffold the students (IS) to reach the learning goals (GO). Moreover, we investigated more richness in the three separate PCK components.

Mainly, the teachers described the learning goals in more details. For example, the teacher EST3 wants students to learn "Assessing risks and benefits about e-cigarettes." The skills he wants students to develop require that students learn about "particles model." This link is clear when he says that one of his goals is that students "Apply the particles model to analyze what happens in their surroundings" and "Apply science to issues of social relevance." The previous knowledge that students need to have referred to scientific content: "Students must know about the particles model." This will enable them to achieve the content-related goals of this lesson for example, "Represent how particles move in an electronic cigarette" and then, "Use this knowledge to practice the skill of assessing risks and benefits."

Another indicator of the strong development of PCK for SSI was teachers' *understanding of students' difficulties with SSI goals and strategies.* The controversy character of the SSI lesson, the dilemma and the uncertainty it includes, challenged the students. Teachers reached a better understanding of their students' difficulties (SU) with the help of the strategies in the materials, which they used in their lessons. For example, they discovered students' difficulties during collaborative work, discussions, the process of finding and supporting their arguments. EST1 reported: "It was difficult for them [the students] to understand that they had to determine themselves which pieces of evidence were reliable." Likewise, EST4 said: "The most critical moment was when the students had to argue for an opinion because they were afraid of making a mistake and they are not used to doing this in the classroom."

Another source of students' difficulties was that the SSI materials made students use science knowledge in a different context than the context they usually do. Additionally, teachers mentioned that the materials helped them to be aware of the students' alternative ideas and beliefs that prevent them from critical thinking or decision making.

Suggesting appropriate SSI instructional strategies was also included in strong development of PCK for SSI. The SSI materials supported the insertion of a new instructional strategy into the lesson. "The cards helped to focus the arguments and base them on the provided information." (ILT9). When the teachers understand the students' difficulties in the SSI-based science lesson to achieve the learning goals of the lesson, they reflected on the instructional strategies they used and shared their ideas for using more appropriate instructional strategies and improving their skills to use the suggested strategies more efficiently next time. For example, the teacher CYT2 mentioned: "The students had great difficulties with the argumentation activity…It was something new for them, they felt uncertain, and they wanted to confirm the answers with me all the time." After noticing the students' difficulty and explaining the reason of it, the teacher stated her ideas about improving the instructional representations: "I would change the argumentation worksheet to better support the students, and also the way I organise and support the groups." (CYT2).

Another example is the teacher with a general science background (NOT2) focused more on argumentation skills. She used the material in an elective science class, with a focus on research methods, which is a mixed class (8th and 10th graders) with large differences between the students' levels. Although she planned the lesson well with a detailed lesson plan beforehand, not everything worked in the way she had planned. She added an extra lesson for the students to find their arguments and evidence online. The students found the arguments but did not manage to use them properly. The teacher learned that she needs to prepare a structure for this next time and she mentioned:

> … To use ready-made arguments is too simple. A good mixture would be best. I could have given out some articles/papers in advance; we could have extracted the arguments together and put them in an argument bank, which they could pick from later. (NOT2, Post-reflection)

Our analysis revealed that *focusing equally on science content and SSI skills* is another indicator of strong development of PCK for SSI. The SSI materials that the teachers enacted offered a change in teaching practice. The teachers who used more elaborated materials, or adapted the materials to make them more challenging in a way to include more science content, diverse teaching strategies and activities for developing SSI skills showed strong PCK development for SSI. Furthermore, these teachers also planned content related learning objectives, in addition to the skills objectives that the materials offer, and focused on both types of objectives during the instruction. They put emphasis equally on science content and SSI skills objectives during the lessons.

For example, EST3 focused on teaching science content (particles model) and developing students' skills (e.g., assessing risks and benefits, making informed decisions about e-cigarettes). His instructional strategies were consistent with the objectives of the lesson, as he invested time and effort on this during the lesson (from the lesson observation). Moreover, he assessed students' learning both on the content (particles model, the behavior of particles, by making students draw, by collecting the drawings) and on the skill (assessing risks and benefits about e-cigarettes, by discussing) objectives. He made an effort to bridge the science content and SSI skills and made the students aware of this link. Table 3 summarizes this group of teachers that showed strong development of PCK for SSI.

TABLE 3 Strong development in PCK for SSI

Teacher	PCK components developed	Interconnection between PCK components	Material	Student age (years)	Science major
NOT2	SU & IS & AS	GO & US & IS & AS	Eating Insects	13–16	General science
EST3	GO & SU & IS	GO & US & IS	e-Cigarettes	15	Chemistry
EST4	GO & SU & IS	US & IS	Big Bag Ban	15	Chemistry
ILT2	GO & SU & IS	SU & IS & GO	Ban Cola	15–16	Chemistry

Abbreviations: PCK, pedagogical content knowledge; SSI, socioscientific issues.

7.2.2 | Intermediate development in PCK for SSI

When there is growth in two PCK components, and these components are interconnected with coherent reasoning of a teacher this was defined as intermediate development in the teacher's PCK for SSI. Table 4 summarizes this group of teachers and their PCK development.

Intermediate PCK for SSI includes strong *interconnections between the two developed PCK components*. For the teachers who developed IS and SU components, these two components were consistent before the lesson only regarding the science content. However, after the lesson the teachers learned more about the students' difficulties and needs regarding making and using arguments, applying science knowledge to solve a societal problem/dilemma, working in groups and discussing. Being aware of the student's needs, they suggested appropriate IS such as using discussions, argumentation, introducing dilemma, scaffolding students to apply science knowledge in solving a real problem, and using group work techniques. *It appeared that these two components are interconnected strongly, and there is more consistency between them after the lesson*. For example, teacher CYT5 stated in the post-reflection about students' difficulties (SU):

> The main problem that I had in this lesson was that the students did not have the necessary knowledge. Even though in the schoolbooks we have similar concepts and content, the students were not able to make the connection to what we were discussing. (CYT5)

TABLE 4 Intermediate development in PCK for SSI

Teacher	PCK components developed	Interconnection between PCK components	Material	Student age (years)	Science major
CYT1	SU & IS	SU & IS	Death to Diesel	15–16	Chemistry
CYT2	SU & IS	SU & IS	Ban Cola	11–12	General science
CYT4	SU & IS	SU & IS &GO	Sinking Island	12–13	Chemistry
CYT5	SU & IS	SU & IS & GO	Life on Enceladus	13–14	Chemistry
EST2	SU & IS	SU & IS	Ban Cola	15	Chemistry
EST5	SU & IS	SU & IS	Car Wars	14	Chemistry
NOT6	SU & IS	SU & IS	Sinking Island	16–17	General science, Maths, Physics
ILT4	SU & IS	SU & IS & GO	Ban Cola	15–16	Chemistry
ILT1	GO & IS	GO & IS	Car Wars	13–14	General science
ILT5	GO & IS	GO &IS	Death to Diesel	15–16	Chemistry
ILT7	GO & IS	GO & IS	Three Parents	17–18	Bio-technology
ILT9	GO & IS	GO & IS	Big Bag Ban	15–16	Chemistry
CYT3	GO & SU	GO & SU	Electrical Appliances	15–16	General science
CYT6	GO & SU	GO & US & IS	Ban Cola	8–10	General science
EST1	GO & SU	GO & SU & IS	Life on Enceladus	15	Physics
ILT3	GO & SU	GO & SU & IS	Three Parents	17–18	Bio-technology
ILT6	GO & SU	GO & US & IS	Ban Cola	15–16	Chemistry

Abbreviations: PCK, pedagogical content knowledge; SSI, socioscientific issues.

Moreover, about IS, he shared some detailed ideas after the lesson:

> So, what I suggest is to divide the lesson to sub-lessons that will be taught in multiple lessons. We need more time. In this way, the lessons and activities will be more detailed. For example, in 'Life in Enceladus' [SSI material used in the lesson] we could have an activity about the solar system, the positioning of the planets around the sun, and the satellites of planets. In another lesson, we could discuss how the earth was created and how hydrogen cyanide had a part in this. In this way, we could have teaching in which students will have enough information and will be well informed to interpret the evidence provided to them and come to a conclusion. (CYT5)

Teachers who developed GO and IS PCK components mentioned more SSI goals. For example, educating future citizens who are responsible, can think critically, deal with uncertainty, dilemma, and make informed decisions. Moreover, *they were more aware of the need to use diverse instructional strategies to meet the SSI goals.* Even though they had clear goals, after the lesson, they learned more about appropriate strategies and timing of the activities to reach the SSI related goals. For example, they learned that they would use critical thinking, discussion, and other strategies that allow addressing the ethical and religious aspects of a socioscientific dilemma to meet the learning goals. Additionally, the need for longer sessions for group discussion was highly recognized.

7.2.3 | Weak development in PCK for SSI

When there is development in one PCK component, and this component is interconnected to another PCK component, this defines weak development in PCK for SSI. Table 5 summaries this group of teachers and their PCK development.

For *the teachers who developed AS component,* we figured out *more interconnection between AS and GO components.* After the lesson, through reflections, the teachers realized that the learning objectives were not formulated measurably, and they developed understanding and knowledge to change this next time.

Moreover, weak development in PCK for SSI was characterized by *lack of connecting students' needs and instructional representations.* Teachers who showed weak PCK for SSI lacked connecting their understanding of students' difficulties with the ways to support them during the SSI lesson. Although they understood their students' needs and difficulties regarding SSI lesson, they did not use appropriate instructional representations to scaffold the students. For example, the teacher NOT3 wanted the students to present their arguments regarding eating insects. The students had problems

TABLE 5 Weak development in PCK for SSI

Teacher	PCK component developed	Interconnection between PCK components	SSI material	Student age (years)	Science major
NOT3	IS	IS & SU	Eating Insects	12–13	General science/Maths
NOT5	AS	GO & AS	Ban Cola	11–12	Arts and Crafts
ILT8	AS	GO & AS	Sinking Island	13–14	General Science
EST6	SU	GO & SU	Ban Cola	14	Chemistry

Abbreviations: PCK, pedagogical content knowledge; SSI, socioscientific issues.

in making their arguments and explaining why their insect menu should be chosen ("Eat Insects" lesson). The teacher's instructions for the activity were not sufficient to support the students, and she did not extend her instructions or provide extra scaffolding to her students. However, in her post-reflection she was aware that she should have given better instructions and help more to the students. She stated: "I would have planned the part around making the insect dish menus better, and guided the students to work more. I would also have been more prepared regarding the relevant arguments and justifications. As commented on by the students, we should also have had more plenary discussions." (NOT3).

Another indicator for weak development of PCK for SSI teaching was *lack of balancing the science content and SSI skills goals.* Although teachers mentioned both types of goals, our analysis revealed that they mostly focused on the SSI skills goals (e.g., argumentation, express opinions in a reasoned way and based on scientific evidence) during the lesson, and they did not make strong connections with science content. For example, during the discussion activity, "the students' discussions were hampered by insufficient science knowledge" (NOT3).

8 | DISCUSSION AND IMPLICATIONS

Prior work has documented the effectiveness of teaching SSI on students' learning (Simonneaux & Simonneaux, 2009b; Zeidler et al., 2005). Moreover, several studies have shown that teaching SSI is challenging for teachers (Abd-El-Khalick, 2003; Sadler et al., 2007). Although there are studies that focus on the impact of specially designed PD programs (Dawson & Venville, 2011; Saunders & Rennie, 2013), there are limited studies on how teachers who do not attend such programs develop their knowledge of SSI teaching (Tidemand & Nielsen, 2017). In particular, there is little known about what happens to teacher PCK for SSI during teaching SSI (Han-Tosunoglu & Irez, 2017; Han-Tosunoglu & Lederman, 2016).

The main aim of this study was to explore science teachers' PCK development during the enactment of a single SSI module. We investigated PCK development and characterized the quality of the teachers' PCK organized around four components of PCK as suggested by Magnusson et al. (1999). Knowing about the development of PCK and the characteristics of PCK for SSI provides insights into short-term teacher PD.

Our data analysis suggested the indicators of stronger and weaker development of PCK for SSI teaching. Strong development of PCK for SSI teaching includes "Strong interconnections between the PCK components," "Understanding of students' difficulties in SSI learning," "Suggesting appropriate instructional strategies," and "Focusing equally on science content and SSI skills." Our findings point to the importance of these aspects of PCK development for SSI teaching. We argue that when PD programs and curriculum materials focus on developing these aspects, they will contribute to strong PCK development for SSI teaching.

This finding extends those of Alonzo and Kim (2016), Barendsen and Henze (2017), and Park and Chen (2012) confirming that the strong interconnections between the PCK components lead to strong PCK development. Moreover, Alonzo and Kim (2016) pointed out that strong declarative PCK includes a deep understanding of student thinking. Our study confirms this finding since one of the indicators for strong PCK development is understanding of students' difficulties in SSI learning. We also found strong interconnections between *understanding of students' difficulties* in SSI learning and *suggesting appropriate instructional strategies* in SSI lesson. Understanding students' difficulties stimulated teachers to think about appropriate IS and ways of guiding students during an SSI lesson and this synchronization contributed to strong PCK development for SSI. This finding provides support for the study of Park et al. (2011) where they found that the IS and SU components of PCK are interconnected strongly during reform-based science teaching. We consider SSI teaching as a reform-based science teaching, and we also investigated strong interconnection between IS, US, and GO components of PCK for SSI.

On the other hand, our findings proved that the opposite of this statement is also true. That means, we investigated that *lack of connecting students' needs and instructional representations* is an indicator for weak development of PCK for SSI teaching. Therefore, when a teacher's PCK of these two components developed without an interconnection between them so, a teacher's reasoning for these two components is not coherent, PCK develops only weakly.

Although it is not surprising to find out that focus on science content indicates strong development of PCK, our findings suggest that *considering science content and SSI skills goals equally important* is an indicator for strong development of PCK for SSI teaching. In their study, Tidemand and Nielsen (2017) found that the teachers' primary goal was to teach the science content and they used SSI as instruments to engage students, and show the importance of the science content in a given context. However, our finding reveals that teachers with strong PCK development put equal emphasis on science content and developing SSI skills. In this way, this finding extends the previous work in SSI teaching and teacher knowledge. We can argue that by having a science major and being experienced in science teaching this group of teachers felt more comfortable in focusing SSI goals next to science content goals. Having solid content knowledge, the teachers can devote their attention to pedagogical aspects of the SSI lesson. This conclusion is in line with the findings of Angell, Ryder, and Scott (2005) where they discovered that the experienced teachers made strong connections between science content knowledge and pedagogical skills.

On the other hand, the *lack of balancing the science content goals and SSI skills goals* during SSI-based instruction is appeared to be an indicator of weak PCK development. The teachers who showed weak development of PCK for SSI mostly focused on the goals for developing SSI skills and ignored the student difficulties regarding science content. The reason for this can be that teaching SSI requires different pedagogies that are unfamiliar to the teachers (Ekborg et al., 2013). In addition, teaching SSI puts demands on teachers to move out of their comfort zones by demanding knowledge from outside their scientific domains (Simonneaux & Simonneaux, 2009b).

The findings regarding the development in the components of PCK for SSI provide compelling evidence that science teachers can develop aspects of their PCK for SSI with the use of a single module since 25 teachers (out of 30) developed one or more PCK components, where 21 teachers showed strong or intermediate PCK development for SSI. Most of the teachers developed their knowledge about *students' understanding of science* (*SU*) and *instructional strategies* (*IS*). Regarding SU, the SSI module provided teachers with opportunities to see other aspects of their students' knowledge. They became more aware of their students' diverse needs, and interests. This is very important for effective SSI teaching because as a student-centered pedagogy, it is essential that teachers become aware of students' previous knowledge to build SSI instruction from that.

Regarding IS, the materials provided immediate scaffolding to teachers for teaching SSI in science classes. They learned and adopted typical SSI instructional strategies such as discussion, argumentation, and introducing socio-scientific dilemma in their teaching. This finding is promising, especially given that previous studies have focused on long-term PD to support the development of PCK (Davis & Krajcik, 2005; Shulman, 1987) or teachers' understanding of SSI (Saunders & Rennie, 2013). Furthermore, it also illustrates the significance of the act of teaching to the development of teachers' knowledge of students' understanding. As teaching is such a complex craft one cannot learn just from the literature about students' understanding, misconceptions, and competencies. Teaching practice allows a teacher to grasp much knowledge.

The least development appeared in the knowledge of the *assessment component* of PCK for SSI. Most of the teachers used the SSI materials in a single and separate lesson and did not integrate it into their current curriculum, so they did not plan to assess students' learning. Another explanation is that, as previous research states, the SSI context and the skills that the materials aim to improve were new for the teachers, and the teachers lacked the knowledge of appropriate assessment methods and instruments (Evagorou, 2011; Levinson & Turner, 2001; Tidemand & Nielsen, 2017). Furthermore, as most modules did not put a strong emphasis on assessment, we see only a weak development in teachers' PCK regarding this aspect.

This finding confirms the previous research that suggests using curriculum materials fosters teacher learning and teacher PCK development, especially regarding *knowledge of instructional strategies,* and *understanding students' diverse needs* (Beyer et al., 2009; Beyer & Davis, 2009; Gess-Newsome et al., 2010; Remillard, 2000; Schneider, 2006; Schneider et al., 2005; Schneider & Krajick, 2002). Consistent with prior research, we also captured the most development in IS and SU components of PCK for SSI during the enactment of the materials.

Furthermore, our findings are in good agreement with the other studies which argue that curriculum materials support teacher learning especially about adapting and implementing new approaches and new representations of science content into practice. In their study, Grossman and Thompson (2004) and Schneider and Krajick (2002) have illustrated that educative curriculum materials guide classroom practices of teachers in applying reform-based approaches, new representations of science knowledge, and teaching outside of their subject area. Our study confirms this finding because teaching SSI requires knowledge and skills outside the teachers' subject area, and teachers need to introduce science knowledge in different ways than usual. Indeed, our analysis revealed that the materials supported teachers in both aspects while teaching SSI.

We speculate that the development of PCK for SSI teaching has been supported by the nature of the curriculum materials. The most dominant aspect of the modules that the teachers enacted is the inclusion of well-structured instructional strategies that are suitable for teaching socioscientific topics, namely: Argumentation, critical thinking, and decision making are all interwoven with an authentic dilemma and science content. Most teachers captured this characteristic of the materials, as can be inferred by the findings, yet further investigation is needed about this. The next step of our research could be studying which specific features of the materials can be attributed to teachers' PCK development.

Specially designed curriculum materials can be used in pre- and in-service teacher training. As our findings suggest, even with teaching a single module teachers' PCK for SSI can be developed. Especially for the teachers who cannot attend long PD programs, specially designed SSI materials can be used instead of long PD courses.

Most notably, this is the first study to our knowledge to investigate the development of teacher PCK for SSI during the enactment of a single module of curriculum materials. Our results provide compelling evidence for developing teacher PCK for SSI especially SU and IS components of PCK, using specially designed curriculum materials.

It is interesting to note that although SSI is a domain that inherently takes into consideration cultural differences, no significant differences were found among the teachers from different countries. This can be due to the fact that all participating countries were European; therefore, there are more similarities than differences among the teachers. Another interesting explanation comes from strong congruity that was found when looking for cross-cultural differences and similarities regarding epistemological orientations to SSI among students (Zeidler, Herman, Ruzek, Linder, & Lin, 2013). It could be that similar epistemological orientations to SSI result in similar PCK development among teachers from different countries. Zeidler (2002) offers a new look at the relations between subject matter knowledge, pedagogical knowledge, and PCK. He raises two points that are relevant to our research. The first is that even if we can show that an individual teacher underwent development in her PCK for SSI, still we need to be concerned for the issue of how the larger institutional and educational context (colleagues, management, administration, and credit policy) support this development in PCK. The second is that our research represents more the approach of the social behaviorists, which focus more on the ready-made curriculum, and the ability of teachers to transfer it to the students, rather than the process-based curriculum. However, we strongly argue that the main purpose of the intervention presented in this study is to construct meaning rather than to transfer knowledge.

The present study also has some limitations. Making teachers reflect on the lesson also influences the development of teacher knowledge. In the present study, the teachers used specially designed curriculum materials by planning, enacting, and reflecting on SSI teaching. Teacher reflection upon classroom practice has been associated with an improvement in teacher knowledge. In particular, several studies associated teaching practice and reflection with teacher PCK development (e.g., Clarke & Hollingsworth, 2002; der Valk & Broekman, 1999; Van Driel & Beijaard, 2003). It means if the teachers had used the materials without any preparation and reflection afterward, the development of teachers' PCK could have been less significant.

The decision to focus on a single lesson in a context that is not the core context of teaching chemistry also has methodological merit. The investigated unit was well defined, aligned with SSI curricular approach, and allowed us to refer the findings to this single experience. However, we cannot isolate the broad context of which science has been taught. Although we do bear in mind that it is never possible to isolate variables in the educational field, we need to strive for a research-design that will allow us to infer our findings to the intervention. In this regard, enactment of a series of modules would provide rich data and better insight. Moreover, a lesson study approach could also be used in future research to study the development of PCK for SSI teaching.

9 | CONCLUSIONS

Our research hypothesis that teacher PCK for SSI will develop, and becomes richer by teaching socioscientific curriculum materials is supported by the findings. We could establish a relation between using the curriculum materials and the development of PCK components, even after a single use of the materials. This implies that for developing teacher PCK for SSI teaching, curriculum materials can be used as effective tools. Teacher trainers, for both pre- and in-service, would benefit from specially designed curriculum materials to foster the development of PCK for SSI if they want their teachers to have strong development of PCK for SSI teaching.

It is already known that through practice teacher PCK grows. Our research pointed out the indicators of the development of strong PCK for SSI. Thus, while designing curriculum materials or PD programs to foster teacher PCK development for SSI, these indicators can be considered. We conclude that the design of materials or PD programs that consider these indicators could better support teachers for SSI teaching.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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