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A Qualitative Meta-Synthesis of Science Education Studies Regarding Pedagogical Content Knowledge

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ABSTRACT

This meta-synthesis aims to address themes and codes of pedagogical content knowledge (PCK) studies in science education. The PCK studies in science education were synthesized and systematically analyzed. A total of 12 studies were examined via the criteria. Three main themes were identified: the development and engagement of the PCK, the relationships between PCK components, and other relationships (belief, attitude, perception etc). The synthesis elicited two dimensions, namely the background and development of the PCK. Also, the results revealed that teachers demonstrated different developmental levels of the PCK and their PCK levels gradually progressed. In addition, it was found that each component of the PCK evolved in different forms. The meta-synthesis emerged two recommended categories of further research on the PCK and its relationships.

Keywords: Meta-synthesis, pedagogical content knowledge, science education.

INTRODUCTION

Even though the quality of education in developing and changing world has always been debated, the quality of the teacher has still been on the agenda. Here, some researchers have focused on teacher knowledge given the philosophy that *nobody can teach anyone else without knowing it* (Ball, 1988; Hashwesh, 1987). Shulman (1986) stated that evaluating teacher's subject matter knowledge was a lost paradigm in that knowledge or pedagogical knowledge alone was insufficient for effective teaching. Furthermore, Shulman viewed pedagogical content knowledge (PCK) as necessary knowledge for an effective science teaching. In the first PCK model developed by Shulman (1987), teachers need seven types of knowledge: a) content knowledge; b) general pedagogical knowledge; c) knowledge of instructional programs; d) knowledge of student characteristics; e) knowledge of the educational system; f) knowledge of educational objectives, values, and historical and philosophical background; and g) PCK.

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The PCK acts as a cornerstone for teacher's knowledge. If the PCK is described or modeled with formulas, the main objective is to focus on the importance of teacher education. Therefore, studies with pre-service teachers are emphasized to follow any change in their PCK levels (Rollnick, Bennet, Rhemtula, Dharsey & Ndlovu, 2008). The PCK studies in science education have attracted an international discussion to improve the qualities of teachers. For example; science teachers should know *science better than knowing more science* (Kind, 2009). However, the PCK may not be fully applicable as claimed. That is, the PCK involves not only teacher knowledge but also its transferring to the students. Hence, the PCK refers the transferability of teachers' science learning experiences to students. Since this particular knowledge (the component of concept and pedagogy knowledge) varies among experienced teachers, the PCK is important in the teacher's professional status (Lee & Luft, 2008).

Theoretical Framework

After the first PCK model by Shulman (1986), researchers have conceptualized different models by adding new components. Grossman (1990) emphasized teachers' in-class practices identifying four basic areas of teacher knowledge (general pedagogical knowledge, subject knowledge, PCK, and contextual knowledge). Grossman (1990) defined the components of the PCK as the objectives for teaching the subject, knowledge of student perceptions, knowledge of the curriculum, and knowledge of teaching strategies. van Driel, Verloop, and de Vos (1998) considered the PCK as a form of practical knowledge and suggested that the PCK was structured through teachers' knowledge and experiences. In addition, Magnusson, Krajcik, and Borko (1999) viewed the PCK as *a transformation of knowledge for teaching,* and expressed it as an understanding of how a teacher can help his/her students comprehend a specific topic. Despite many PCK models, science education studies have preferred this one (De Jong, van Driel & Verloop, 2005; Lee & Luft, 2008). According to this model, the PCK of science consists of five components: orientation information, science curriculum knowledge, science assessment knowledge, science teaching strategies knowledge, and knowledge of student understanding in science teaching. In the model, the goals and objectives of science teaching regarding a specific subject constitute the orientation component toward science. This component concentrates on two main questions "what do teachers teach?" and "how do they assess it?" Therefore, the reciprocal relationships between science orientation information and the other components of the PCK emerge. However, some researchers have related the dynamics of PCK to classroom practices and experiences (Alanzo & Kim, 2016). In view of Nilsson (2008), many PCK studies have not considered teachers' in-class activities that may lead to obtain healthy outcomes. Alonzo and Kim (2016) see the PCK as a non-stationary and dynamic process that serves to the decision-making mechanism of instruction. Therefore, class practice is important for the PCK. Based on the PCK process of Alonzo and Kim (2016), Melo, Cañada, and Mellado (2017) identified three levels (declarative, design, and action in the investigation of the PCK). These levels reflect teacher's thoughts, plans, and teachings of certain topics. Accordingly, these levels are selective in the process of professional knowledge development and change. van Driel, Berry, and Meirink (2014) mentioned the need for teachers to provide collaborative learning environments to ensure the development of the PCK and opportunities during the lesson planning, implementation, and evaluation phases.

Goodnough (2006) contends the need for science teacher educators to have strong subject matter knowledge and PCK, because the PCK develops only through classroom practices. Teacher can develop these practices in their schools and universities through teacher educators. Because of the complex nature of the PCK and its non-verbal knowledge structure, researchers have used different measurement tools to measure it (Loughran, Milroy, Berry, Gunstone & Mulhall, 2001; Schmelzing et al.,2013; Smith & Banilower, 2015). Loughran et al. (2001) measured the PCK of science teachers through two qualitative measures, namely Content Representation (CoRe) and Pedagogical and Professional-experience Repertoire (PaP-eR). Given these tools, each PaP-eR component aims to primarily unveil one of the PCK components of teacher-based classroom observations and their comments on the CoRe. PaP-eR contains the teacher's actions and thoughts of science teaching. The PaP-eR narrative is accessible for the readers to provide a perspective of the PCK. PaP-eR purposes to give the reader a more holistic viewpoint than a CoRe. CoRe is a proposal representing the teachers' PCK of teaching a subject. PaP-eR is a presentation of elements including teachers' thoughts of their PCK (Mulhall, Berry & Loughran, 2003). Park and Oliver (2008) describe the examination of the PCK through the two tools developed by Loughran et al. (2001) as the PCK on/in action.

The PCK hexagon science-teaching model developed by Park (2005) was underpinned on the components of the models developed by Grossman (1990) and Magnusson et al. (1999). The PCK hexagon model added the component teacher competence to those developed by Magnusson et al. (1999). The hexagon model comprises of six components: orientation in science teaching, knowledge of the science teaching curriculum, knowledge of student understanding in science teaching, knowledge of teaching strategies for science teaching, knowledge of assessment in science, and teacher adequacy. Here, orientation to teaching science refers to beliefs about the goals of science teaching, decision-making in teaching, and the nature of science. Knowledge of the science-teaching curriculum and program material refers to focusing on the curriculum. Knowledge of student understanding in science teaching deals with misconceptions, learning difficulties, needs, interest, and motivation. Knowledge of teaching strategies for science teaching is topic-specific and subject-specific (activities and representations). Finally, the methods of assessment and teacher adequacy are subject- and field-specific (Grossman, 1990; Magnusson et al., 1999; Park, 2005). The last component of the PCK model is teacher adequacy, which refers to teaching-related self-efficacy and beliefs about teachers' abilities to influence students' achievement levels (Tournaki & Podell, 2005). Richardson (1996) relates teacher self-efficacy to specific teaching situations including teaching orientation to the subject area, and contributes to their beliefs about the subject area, their thinking styles, and their teaching choices.

Literature Review

The PCK studies have examined its components in relation to different variables in various contexts since the last decade. For example they have focused on teachers' content and pedagogical development and students' critical thinking skills of the subject practices (Lewis, Perry & Hurd, 2009; Saunders, Goldenberg & Gallimore, 2009), the effect of mentoring on the development of the PCK (Barnett & Friedrichsen, 2015), the PCK outcomes of different practices and courses (Nilsson & Loughran, 2012; Seung, Bryan & Haugan, 2012), contribution of teaching materials developed in different contexts to the development of the PCK (Beyer & Davis, 2012), strategies that contribute to the PCK development (Hume & Berry, 2011), and mapping the PCK components (Park & Chen, 2012). However, studies from different disciplines have investigated only one component of the PCK (Avraamidou, 2013), interrelated-components (Aydin, Demirdogen, Akin, Uzuntiryaki-Kondakci, & Tarkin, 2015), or interactions between a single component and the others (Aydin et al., 2015).

Based on these PCK studies, it is important to identify the basic PCK criteria and highlight unexplored issues for future studies. This study provides a general synthesis and systematic analysis of the PCK studies in science education. So, it aims to find out more

effective suggestions and meaningful results by synthesizing the PCK studies under investigation. This study adopted a meta-synthesis to answer the following questions:
a. What are the general themes of the PCK studies in science education?
b. How does a synthesis of the PCK studies in science education guide the development of the PCK?

METHODS

a) Qualitative meta-synthesis

Meta-synthesis refers to the development of theory, a high-level summarization, and generalization of accessible qualitative findings in practice (Zimmer, 2006). The related literature also describes a meta-synthesis as "meta-ethnography" (Noblit & Hare, 1988), which, according to Noblit and Hare (1988), has seven steps:

a. Determination of work
b. Determination of what is targeted for the work
c. Reading the work
d. Identification of related works
e. Interpretation of other works
f. Synthesis stage
g. Interpretation of synthesis

Accordingly, a meta-synthesis is not merely a superficial survey of the literature, but a methodological approach that interprets the analyses of qualitative researches and provides insights to develop the related field. Adding a *third-level* comment is important to interpret the findings of previous researches. Thus, a new synthesized process creates an alternative way vis-à-vis traditional methods (Britten et al., 2002).

For this reason, this research employed a meta-synthesis of the PCK studies in science education to provide a more comprehensive and new understanding of the PCK. The current study took care not to disturb the structures of the compared studies. That is, it used the explanations and comments of the original researches as data sources.

b) Database search and selection criteria

Systematic database search was conducted between December 2017 and March 2018. During database search, necessary controls were provided. To answer the research questions, the related articles (pedagogical content knowledge [PCK], pedagogical content knowledge in science, and subject matter education/teaching) were searched in the Google Scholar, EBSCO-Host, ERIC, Springer, Taylor and Francis Group, and SAGE Premier databases. The selected studies were published from January 2008 to January 2018.

This study applied the following processes. The first stage of the study reviewed all science education studies. This stage found 23,500 studies. The second phase of the study selected qualitative designs of those studies for further review. However, of the selected qualitative studies, this study excluded theoretical and discussion articles, reviews and editorial work, or those related to the development of the PCK model. The third stage of the study examined the qualitative articles through the following criteria: (a) published in the specified databases, (b) subjected to a peer-review process, and (c) included in prestigious national or international journals. After excluding books and book chapters from the study, the end of the process focused on peer-review criterion. Finally, 12 studies appeared for the meta-synthesis of the PCK literature in science education (Table 1).

Table 1. *A list of the studies under investigation in regard to the criteria*

Author, year of publication and country of the study	Aims	PCK components in the studies	Science subjects of the PCK studies	Samples of the studies	Data collection	Data analyses
Appleton (2008), Australia	To examine the effect of mentoring education on primary school teachers' the developmental levels of the PCK	Science content knowledge and in science PCK (such as knowledge of curriculum, context, general pedagogy, and students)	Elementary science	2 female teachers	Interviews, extensive field notes of lessons, lesson plans/ documents, observation	Case descriptions, narratives
Rollnick et al. (2008), South Africa	To examine the effect of subject matter knowledge on the PCK	Subject matter knowledge, knowledge of instructional strategies, knowledge of science curriculum	Chemistry- Chemical equilibrium and teaching mole	1 male, 1 female teacher	Interviews, observations, teacher resources such as textbooks, materials, tests, and past examination papers.	PaP-eRs and CoRe
Goodnough and Hung (2009), Canada	To examine primary school teachers' developmental levels of the PCK concerning problem-based learning approach	Orientations to teaching science, knowledge of students' understanding, knowledge of science curriculum, knowledge of instructional strategies, knowledge of assessment in science.	Elementary science	5 female teachers	Videotaped teaching sessions, interviews, electronic journal entries, documents and materials	Constant comparison analyses
Seung et al. (2012), USA	To examine the effect of the course (which is given to physics graduate teaching assistants) on the PCK	Knowledge of curriculum goals, knowledge of instructional strategies, knowledge of students' learning.	Physic- Matter and interaction	5 male graduate teaching assistants	Observations, digitally recorded video, interviews, written reflections, and researchers' field notes	Deductive and inductive data analysis
Boesdorfer and Lorsbach (2014),USA	To look for any response to the following question "Can a teacher's orientation toward science teaching be used to understand her actual teaching practice?"	Orientations to teaching science	Chemistry- The periodic table	1female teacher	Interviews, observations, and teaching documents	Constant comparison analyses
Mthethwa-Kunene, Onwu, de Villiers (2015), Swaziland	To investigate the PCK of the experienced biology teachers and its development of the genetic concept	Teacher content knowledge, pedagogical knowledge and knowledge of students' preconceptions and learning difficulties	Biology- School genetics	3 females and 1male teacher	Concept map, interviews, lesson observations, post-lesson teacher questionnaire and documents	Scoring the concept maps, document analysis
Barnett and Friedrichsen (2015), USA	To examine the effect of the teaching strategies applied by a biology	Orientations to teaching science, knowledge of students' understanding, knowledge of science	Biology- DNA/Protein Synthesis and Evolution	1female mentor teacher	Audio-recording, daily planning, reflection, and	Constant comparison analyses

	mentor teacher on a pre-service teacher's PCK level	curriculum, knowledge of instructional strategies, knowledge of assessment in science			teaching-related conversations	
Bravo and Cofré (2016), Chile	To examine the development of the PCK of two biology teachers involved in a Professional development program on human evolution	Knowledge of students' understanding, knowledge of science curriculum, knowledge of instructional strategies, knowledge of assessment in science.	Biology-Human evolution	1 male and 1 female teacher	Interviews and CoRe	Content analysis, CoRe and PaP-eRs
Demirdögen (2016), Turkey	To go over relationship(s) between orientation information component and other components	Orientations to teaching science, knowledge of students' understanding, knowledge of science curriculum, knowledge of instructional strategies, knowledge of assessment in science.	Nature of science	5 females and 3 males pre-service teachers	Open-ended questions, associated semi-structured interviews, CoRe	Deductive and inductive data analysis
Melo et al. (2017), Colombia	To search the relationship(s) between PCK and emotions in teaching.	Knowledge of instructional strategies, knowledge of science curriculum, knowledge of students' understanding, subject matter knowledge	Physics-Electric field	1 male, 1 female teacher	Open-ended questionnaire, semi-structured interview, CoRe	Content analysis
Lampley, Gardner and Barlow (2017), Southeastern United States	To investigate changes in graduate teaching assistants' PCK levels after participating in lesson study.	Orientations to teaching science, knowledge and beliefs about science curriculum, knowledge and beliefs about students' understanding of specific science topics, knowledge and beliefs about assessment in science, knowledge and beliefs about instructional strategies for teaching science	Biology-General biology	2 males and 2females graduate teaching assistants	Reflections, interviews, audio recordings of lesson study, researcher journal of meeting and classroom observations, field notes of classroom observations	Cross-case analysis
Soysal (2018), Turkey	To explore the components of the PCK of an experienced elementary science teacher and to reveal the presumed interactions among these components	Orientations to teaching science, knowledge of students' understanding, knowledge of science curriculum, knowledge of instructional strategies, knowledge of assessment in science.	Elementary science	1 female teacher	Semi-structured interview	In-depth qualitative analysis, enumerative approach

Accordingly, the present study included 12 qualitative research articles (four from the USA, two from Turkey, and one each from Australia, South Africa, Canada, Swaziland, Colombia, and Chile) published from 2008 to 2018 in internationally acclaimed journals and available in full text. The samples of the studies ranged from one to five individuals and involved teachers, pre-service teachers, graduate teachers, or teachers or mentors. These studies clearly indicated the PCK components and principally contained science and other science disciplines (i.e., physics, chemistry, biology). Their data collection tools used such qualitative methods as interviews, reflections, concept mapping, field notes, videotaped teaching sessions, documents, and materials. However, some studies employed the CoRe and PaP-eR (Bravo & Cofré, 2016; Demirdogen, 2016; Melo et al., 2017) as the method of data analysis (Bravo & Cofré, 2016; Rollnick et al., 2008). Most of the studies examined the impact of any treatment or course on the PCK and its development. In addition, almost all of these studies used case study approach as a qualitative research method (Appleton, 2008; Barnett & Friedrichsen, 2015; Boesdorfer & Lorsbach,2014; Bravo & Cofré, 2016; Demirdogen, 2016; Mthethwa-Kunene et al., 2015; Rollnick et al.,2008; Seung et al.,2012; Soysal, 2018).

c) Data analysis

This meta-synthesis study followed the analysis steps specified by Noblit and Hare (1988). The first stage covered the aims and objectives of the study. The following steps embraced to examine and determine relevant studies and criteria. Then, the present study classified them about the relevant criteria and the scope of the current study. Later, the present study summarized them for the meta-synthesis. The studies were also exposed to the content-analysis using Nvivo 10 software. The first phase of encoding yielded a large number of codes. Afterward, the obtained codes were assigned to categories and similar/different codes or the related nodes. The last stage identified themes and implemented reliability procedures. For peer-reviewing procedure, the codes were sent to another researcher, who had worked on the PCK. The coincidence coefficient of sentences and codes was calculated. Cohen's kappa compliance coefficient was determined to be .87. Bazeley and Jackson (2015) imply that the kappa-1 value demonstrates a perfect fit, and close values to this value are also very good for the appropriateness of encodings. During the analysis, the researchers repeatedly read each study based on the research questions and made necessary controls. Thus, a long-term interaction with the research data prevented personal prejudices. The next step, termed "reciprocal translation" by Noblit and Hare (1988) incorporated to synthesize the studies and uncover new aspects. The final stage of the synthesis explained the findings along with their dimensions while remaining faithful to the original studies.

d) Validity of the Study

A quality index can be used in meta-synthesis studies according to the interest model (Fingfeld, 2003; Jones, 2007). Based on this quality index, a meta-synthesis needs to ensure credibility, compatibility, and controllability. Credibility recognizes convincing explanations or interpretations. Credibility increases when raw data from the original studies are supported (Jones, 2007). The present study directly supported the citations of the studies under investigation to ensure the credibility of the meta-synthesis. Compatibility needs to conform the findings to the outside of the meta-synthesized studies, and focus on working life experiences as well as typical and nonexistent elements. While comparing a meta-synthesis with the theoretical literature validates it, this literature may not be infallible (Jones, 2007). This study summarized similar researches in the literature in addition to the studies in the meta-synthesis. The syntheses were presented by comparing the findings of similar studies with related literature. Instability needs to clearly state and use the methods of the meta-synthesis in a sufficiently detailed way. On the other hand, interpreting studies within the synthesis might emerge unique results instead of identical results (Jones, 2007). To ensure the controllability of the meta-synthesis, this study detailed the followed steps in the methods section and provided the findings of primary studies. Furthermore, this study ensured the validity and reliability for qualitative researchers, and explicitly detailed their measures of the meta-synthesis method.

FINDINGS

The findings of this study are presented in this section. The obtained initial themes are development and engagement of the PCK, the relations between the PCK component, and other relations.

a) Development and Engagement of the PCK

This aspect of the study addressed the effects of the approach (i.e., problem-based learning), practice (lesson study/learning study), and training activities (course, professional development, and educative mentoring) on the development and proliferation of the PCK. They addressed some progresses in the PCK through knowledge (Barnett & Friedrichsen, 2015; Mthethwa-Kunene et al., 2015) or components (Rollnick et al., 2008) of the subject area (Barnett & Friedrichsen, 2015; Bravo & Cofré, 2016; Goodnough & Hung, 2009; Hamdani & Oktavianty, 2017; Lampley et al., 2017; Mthethwa-Kunene et al.,2015; Seung et al., 2012). Goodnough and Hung (2009) stated that the implemented activities tend to lead teachers to take more risks. As such, they note the following.

> "Kara and Sharon, who worked as partners in this project, also felt they became greater risk-takers: "Although we had not used PBL before, we allow edourselves to be risk-takers and allowed the students to be risktakers. Students took more control and we had been reluctant to do this in the past" (p.235)

Studies on the PCK in general (content knowledge, pedagogical knowledge) or the subject matter knowledge indicated that the PCK needed to be studied in a topic-specific manner (Mthethwa-Kunene et al., 2015). Mthetwa-Kuene et al. (2015) categorized these methods as interdisciplinary courses offered at universities, classroom experiences, workshops, and post-course reflections. However, they pointed out that each teacher was essentially a history of the PCK, and the implemented activities were effective in recalling the knowledge.

In general, they showed that the implemented activities supported teachers' student-centered approaches, their adoption to specific teaching strategies as well as reshaping their evaluations, and critical reflective skills (Barnett & Friedrichsen, 2015). Bravo and Cofré (2016) reported that these experiences contributed to the teacher's theoretical wisdom and transformation of his knowledge into practice.

> "Regarding the type of PDP experienced, these more complex relationships are produced, according to the teachers, due to their review of and reflection on the lessons they taught. This type of approach, in which PCK modifications are analyzed based on what teachers observe upon reviewing their lessons…..In this sense, after the PDP and follow-up on the lessons taught, the teachers area ware of their PCK on evolution, recognizing the strategies used, future challenges, and new activities that they will perform" (p.2523).

b) Relationships between the PCK Components

The relationships between the PCK and content knowledge included the individual examination of the PCK components or the relationships between them or the subcomponents of a component in the PCK, or the relationships between the subject matter knowledge and PCK. These studies related the context of science teaching to all PCK components. Demirdögen (2016), who highlighted a two-sided relationship between science orientation and other components, represented this relation to an elliptical sphere, and presented "reflection" to every cubic period. Similarly, Rollnick et al. (2008) proposed a new model by establishing a relationship between the PCK and subject matter knowledge. This model added conceptual knowledge to the PCK, and claimed that teaching without conceptual knowledge would not effectively improve the PCK.

Even though there are shortcomings in subject matter knowledge, it affects teachers' classroom practices. In this case, the model explains the importance of subject matter knowledge.

> "Drawing from these various models we extracted four fundamental domains of knowledge for teaching: that is, knowledge of subject matter, knowledge of students, general pedagogical knowledge, and knowledge of context… We have chosen a few of these….namely, subject matter representations, topic-specific instructional strategies, curricular saliency, and assessment" (Rollnick et al., 2008,p.1380-1381).

Boesdorfer and Lorsbach (2014), who examined important components of the PCK, identified the weak and strong aspects of teachers to guide teacher trainees. Boesdorfer and Lorsbach (2014) depicted the interrelated components of the PCK influencing teachers' practices.

> "In this particular case, the relationships that are established, in addition to the change or emergence of a new element in a component, affect and influence another component, triggering the growth in the complexity of both teachers' PCK schemes of evolution" (p.2522).

However, Lampley et al. (2017) reported that the PCK components did not interact with one another because some components of the PCK did not change after the teaching intervention. However, they concluded that while the implemented activities affected teachers' beliefs, they did not influence some components of the PCK.

c) Other Relationships

The studies under investigation have also related the development of the PCK to teachers' beliefs (Appleton, 2008; Goodnough & Hung, 2009), attitudes (Boesdorfer & Lorsbach, 2014; Goodnough & Hung, 2009; Lampley et al., 2017), understanding (Goodnough & Hung, 2009), class practices (Appleton, 2008; Goodnough & Hung, 2009), perceptions (Appleton, 2008), and feelings (Melo et al., 2017). Melo et al. (2017) noted that teachers' PCK levels progressed gradually and its components thereof did not change equally. They also provided several examples for important trends in the development of the PCK.

> "..She acquired new professional knowledge from one year to the other thanks to the combination of positive and negative emotions towards the curriculum, methods, and content catalyzing her changes. Alejandro however, during the first year, showed many positive emotions about the curriculum and methods. This made him feel satins filed and happy with what he was doing, and therefore he did not need to change" (p.1039).

Boesdorfer and Lorsbach (2014) mentioned that the activity in their study influenced the teacher's attitudes toward students, and increased their curiosity and excitement levels of student learning. These also impacted their pedagogical decision-making mechanisms in that teachers felt themselves responsible for student learning and students' motivation or failure levels.

Synthesis

This section evaluated and interpreted the findings of the synthesis through two dimensions (PCK Background and Development of the PCK).

PCK Background. Nearly all of the studies confirmed the effectiveness of the implemented activities on teachers' PCK levels, but its extent was related to teachers' existing PCK. Boesdorfer and Lorsbach (2014) explained that each teacher's classroom experience was unique to enrich his PCK. The teacher's classroom experiences increase over years and makes it easier to understand their teaching practices. Geddis and Wood (1997) defined the PCK as a broad spectrum of pedagogical transformation of subject matter knowledge into pedagogical knowledge and the informative knowledge of instructional strategies. Here, curricular knowledge reflects the teacher's knowledge. Appleton (2008) noted that primary school and other branch teachers had different backgrounds regarding PCK; therefore, they passed through different developmental stages. This explains the specific structure of the PCK. Thus, Appleton (2008) contended that primary school and other branch teachers needed to examine different types of the PCK for pupils. Furthermore, branch teachers tended to develop the PCK in their own ways. However, primary school teachers did not consider the development of the PCK in a different discipline or try to improve it at all.

Development of the PCK. The studies indicated that the implemented approach, activity, or practice totally or partially affected the components of the PCK. Nearly all of the studies developed the development of the PCK and impacted teachers' attitudes, beliefs, and so on. The different approaches/implementations of the development of the PCK highlight the necessity of a flexible strategy in terms of themes and continuity. Goodnough and Hung (2009) reported that even though each new approach had risk factors for the teacher, it was practically successful in achieving its different outcomes. Lampley et al. (2017) stated that teachers might struggle with students in their classrooms when introducing a new practice. However, the effects of students' meanings about classroom practices depend on the success or failure of the teacher. Since successful teachers are more determined to use the new approach, if they continue to do so, they will be more successful in facilitating student learning (Wheatley, 2002).

DISCUSSION and CONCLUSION

This meta-synthesis study examined previous researches on the PCK in science education and identified a number of themes. It has indicated that the dynamic structure of the PCK is open to learning, innovation and development. The implemented activities to develop the PCK have beneficial effects on teachers' general pedagogical knowledge, contextual knowledge, alternative perspectives, student attitudes, and other attitudinal effects on the components of the PCK (Appleton, 2008). However, making these practices sustainable and continuous is important, and calls for conducting regular studies (Seung et al., 2012). In addition, Lampley et al. (2017) emphasizes the importance of content editing. Also, integrating theory into practice is beneficial to develop teachers' PCK.

This meta-synthesis study found that teachers had different levels of the development of the PCK, and gradually progressed its components. In view of Melo et al. (2017), a teacher may turn his traditional education approach into an educational understanding (e.g., student-centered approach, or vice versa). Here, the teacher may have a way to reflect his PCK levels through nonverbal information.

The themes from the examined studies indicated the significance of reflections and other factors (i.e., teachers' emotions, and beliefs). They also have concentrated on an integration of the approach into practicum, and their experiences of class practices. These factors need to be taken into consideration for examining the PCK (Gess-Newsome, 2015), and may guide researchers in terms of other relationships.

The application of the approach or other activities in the study emerged the development of the PCK. Essentially, during the application of a new approach, teachers need to use different learning practices for students. Indeed, these learning practices create risks for the teachers to consider effectiveness of a brief adaptation process (Appleton, 2008). Inability to adequately control its progression may impede a long-term development of the PCK. In this case, a study on mentor applications or knowledge reminders at certain intervals may be considered.

Suggestions

This qualitative meta-analysis, as an in-depth study of the PCK, clarified the "PCK background" and "development of the PCK" in terms of the factors affecting its development. Furthermore, the synthesis indicated that the PCK was not one-way process. Thus, multiple viewpoints of the PCK need to be examined. The environment enriching the PCK has not been fully defined to reveal the shortcomings of "rich-PCK." Because the PCK studies focused on only teachers, future studies should be undertaken to elicit students' perceptions of their teachers' PCK levels. Hence, further studies may be conducted within different contexts and various samples (i.e., colleagues).

There are some limitations of this study. Firstly, the presented study only included peer-reviewed scientific journals, whose publication language was in English. Secondly, the meta-synthesis covered a certain date range (2008 to 2018). Thirdly, in the meta-synthesis only used 12 qualitative studies due to the nature of the meta-synthesis (Bondas & Hall, 2007).

This small-sized study investigated the science education studies of the PCK and provided recommendations for future meta-syntheses. It purposed two categories: the PCK-related research field and the PCK-associated fields. The PCK-related research field concentrates on any change in the PCK components before and after the teaching intervention. The PCK-associated fields, which are related to the effects of the PCK components, call for future studies on the components of the PCK that have not yet been sufficiently considered. Because several factors (e.g., teacher's classroom practices and experiences, course book, student profile, working environment, educational background, and education type) may influence the PCK, future studies should keep these factors in mind. Further, a similar synthesis using evidence-based studies may shed more light on the term "rich-PCK." Follow-up studies ought to inform students about the development of the PCK by listing students-related information in science education (e.g., misconceptions, pre-existing knowledge and environmental learning conditions).

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