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Article

Science Teachers' Pedagogical Content Knowledge (PCK): A Literature Review on Research Questions and Assessment Tools

OUCH SREYPOUV*
**Graduate School of Humanities and Social Science, Hiroshima University, Japan*
Corresponding author's email: d212750@hiroshima-u.ac.jp

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Abstract

Pedagogical Content Knowledge (PCK) has been a critical element of teacher professional knowledge. Meanwhile, research on PCK has been applied in many countries to improve the quality of teacher education and teacher professionalism. Although scholars have distinguished the components of PCK and proposed different means of measuring PCK, there appears to be no clear consensus on how PCK can be found. This paper is a review of science teachers' PCK literature published in the last two decades which the studies of PCK have been impressive. Content analysis of 26 papers included in the review indicated several themes such as the development of PCK, factors affecting teachers' understanding of PCK, assessment tools, and specific regions in which PCK research has been concentrated. For instance, most PCK assessment research has been conducted in the USA. Again, the reviewed papers mostly focused on Biology as compared to other science subjects such as Chemistry and Physics. These insights can be a starting point for researchers, especially those focusing on science education development in the context of the Sustainable Development Goals (SDG 4) which highlight the significance of Science, Technology, Engineering, and Mathematics (STEM) subjects.

Keywords: Pedagogical Content Knowledge; Science teacher; Science education; Assessment tools, Sustainable Development Goals

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1. Introduction

Teaching is a complex profession that requires both knowledge and skills and competencies. The investigation of professional knowledge has commanded increasing attention in teacher education research. Especially the investigation has been made on the domain of teacher knowledge (Shulman, 1986; Shulman & Skykes, 1986; Shulman, 1987; Grossman, 1990). Grossman, (1990) elaborated on the qualification that should be demanded to enter the teaching profession. Teachers should at least have (1) subject matter knowledge, (2) general pedagogical knowledge, (3) pedagogical content knowledge (PCK), and (4) knowledge of context. Subject matter knowledge is comprised of the knowledge of content, syntactic structure, and substantive structure. General pedagogical knowledge includes knowledge of learner and learning, classroom management, curriculum, and instruction. Pedagogical content knowledge covers knowledge of students' understanding, knowledge of instructional strategies, and curricular knowledge.

The knowledge of context refers to the knowledge of community and school. Derived from the work of Carlsen, suggested five domains of professional knowledge for teachers: (1) knowledge of general educational context, (2) knowledge of pedagogy, (3) subject matter knowledge, (4) knowledge about the specific educational context, and (5) pedagogical content knowledge (PCK) (Carlsen, 1999). Even though there was not an agreed worldwide professional knowledge standard for teaching, there was a critical domain called PCK which is most to be paid attention to teacher professional knowledge. The term PCK, which is historical, the origin of PCK work, in general, is accredited to Shulman, 1987. Based on his pioneering work, the first PCK summit was conducted in Colorado State of the United States of America from 20 to 25 October 2012 on the topic of "Notion of Inventing Pedagogical Content Knowledge".

The summit gathered 22 science education researchers from seven countries including the USA to explore and discuss a consensus model/construct of PCK to guide science education research and identify specific next steps in the field of PCK (Berry et al., 2015). The summit was led by Julie Gess-Newsome from Oregon State University, Janet Carlson from Stanford University, and April Gardner from Biological Science Curriculum Study. At the summit, Shulman provided the keynote address about PCK, and other members of the summit shared presentations on the various aspect of PCK. Then the group came up with the proposed operational definition of the PCK "is the knowledge of, the reasoning behind, and enactment of the teaching of particular topics in a particular way with particular students for particular reasons for enhanced student outcomes." (Carlson, 2015 p. 24).

Gradually, Gess-Newsome developed the model of teacher professional knowledge which includes PCK as a component. In his work, PCK has been defined as both a knowledge base used in planning a specific topic in the specific classroom context and as a skill in the act of teaching. Daehler et al (2015) conceptualized the definition of PCK as Shulman defined it. It was a special form of knowledge that goes beyond subject matter knowledge. It is the blend of knowledge of content and pedagogy and making it understandable and comprehensible to the students in the specific context. Many researchers (Amanda Berry et al., 2015; Baxter & Lederman, 1999; Park & Oliver, 2008a) have worked on PCK to identify the strength and weaknesses of its model and guided further research to develop a robust model of PCK. Then the research progress of PCK conceptualization was going on (Ball, et al, 2008; Berliner, 1986; Depaepe et a. 2015). For instance, Abell (2008) defined PCK as the integration and blending of content knowledge and pedagogical knowledge that influence a teacher's decision of teaching method. Building on Shulman's PCK model, Magnusson & J. Krajcik, (1999) developed a model that contains five components of PCK for science teachers: 1) orientation to teaching science, 2) knowledge of assessment of scientific literacy, 3) knowledge of curricula, 4) Knowledge of students' understanding of science, and 5) knowledge of instructional strategies (**figure 1**).

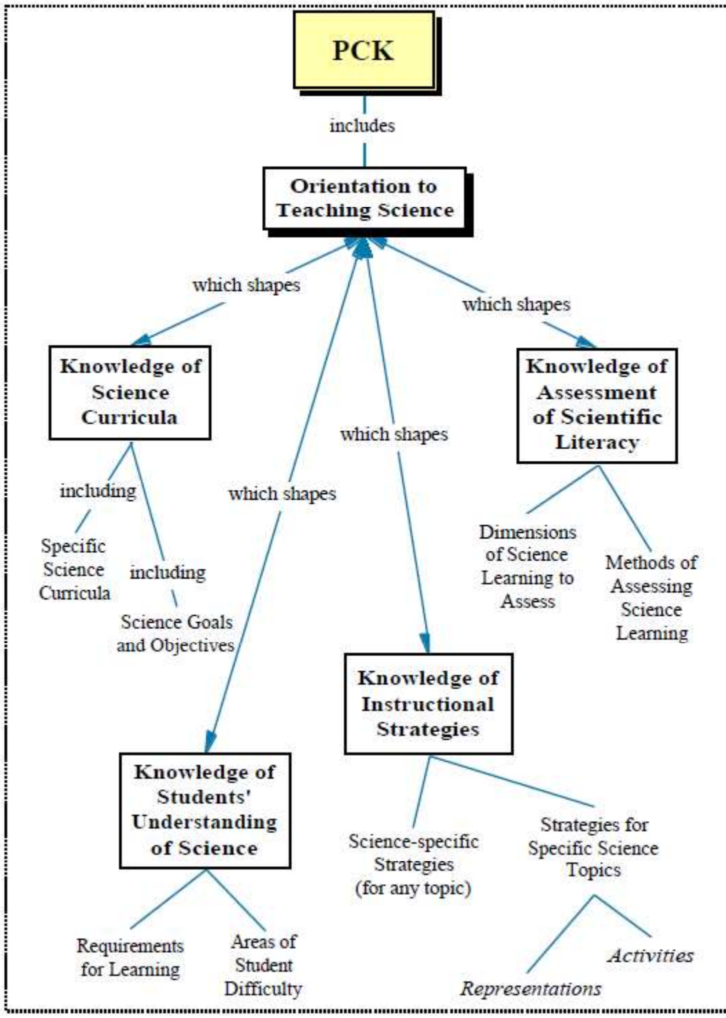

Figure 1: The component of pedagogical content knowledge (Magnusson et al, 1999)

Similarly, to the work of Magnusson, the pentagon model by Park & Oliver, (2008) agreed on the five components of PCK. However, Carlsen, 1999 classified the component of PCK into four as knowledge of students' common misconceptions, knowledge of curricula, knowledge of instructional strategies, and the purpose of teaching science. Even though there is no universal acceptance of the definition, it seems most definitions share a common understanding of PCK as the domain of teacher knowledge which teachers need to structure the content knowledge and choose appropriate teaching strategies for their students. Teachers develop their PCK on particular content through experience and reflection on content knowledge and classroom practice. Developing PCK helps teachers understand the weaknesses of their teaching practice and learn more about the uniqueness of students' characteristics and classroom settings.

PCK research outcomes have been used as the foundation for a discussion on improving teaching quality. To gather the main themes and get an in-depth understanding of what has been done with PCK research, some authors (Schneider & Plasman, 2011; Aydin & Boz, 2012; Depeape, 2013) have focused on systematic or integrative literature reviews to systemize and gather insights from existing studies. Those reviews have identified gaps in the existing research findings, highlighting different thematic areas such as the development of science teachers' PCK, conceptualization of PCK in Mathematics, Biology, etc., and measurement of teachers' PCK. Schneider & Plasman (2011) summarized how science teachers think about PCK components based on their experiences in class and the type of variables that influenced science teachers' knowledge of PCK. Depaepe et al. (2013), elaborated on the conceptualization of PCK in mathematical educational research, the components of PCK, and the countries that had conducted PCK research.

Despite considerable progress in PCK research, there appears to be no clear consensus on how PCK for science teachers can be assessed, especially in subjects such as Chemistry, Biology, Physics, and Earth Science (Baxter & Lederman, 1999). PCK is an internal construct, so we couldn't observe it directly. During teaching, teachers may reveal their strategies which could be observed but it couldn't reveal the reason why teachers chose this part to perform and not the other. Assessing teachers' PCK faces a lot of challenges. To agree on which component to be assessed and which method to be used. (Kagan, 1990; Mikeska et al., 2021 & Park et al., 2020).

Individual PCK varies depending on the content and classroom situation. Thus, there is no fixed PCK that applies to all science topics. Understanding research findings on assessing teachers' PCK, and what science teachers understand about their PCK and development would advantage other science teachers in improving their practice. To be concise, synthesizing previous studies of teachers' PCK would expose the gap in the literature and help science teachers and education stakeholders to gain more insights into how PCK assessment can be developed and implemented. Therefore, this paper reviewed studies of science teachers' PCK published from 2000 to 2021 to build a body of knowledge that can be a foundation insight for improving the assessment of science teachers' PCK and the quality of science teachers.

The following questions are guided in this review paper. First, "what type of research questions have been conducted in the area of science teachers' PCK?" This question would address the type of PCK themes in existing research. Those themes should be elaborated on and distinguished through each study's research question and objectives. Research question two was "What are the valid and reliable tools for measuring science teachers' PCK?". This question focused on the existing valid assessment tools that have been used for measuring science teachers' pedagogical content knowledge. To be specific, the objective of question 2 was to describe the structure of each assessment tool and how to assess it. This question also addressed the strength and weaknesses of each tool.

2. Research Method

This study followed a systematic review (Petticrew & Roberts, 2006). The initial search was conducted on the Web of Science and Education Resource Information Center (ERIC) which include a database of educational research, and mostly peer-reviewed articles. These two sources were determined for the review because they were accessible by the author and had institutional access by Hiroshima university at the time of the study (2021-2022). The search key terms were pedagogical content knowledge, science teacher, and science education which aligned with the objective of this review.

First, placed those keywords on the document search option of Web of Science. it appeared 1081 articles. Then the author refined the results by scoping on publication year, document type, and subject focused. The articles for review were ranged from 2000 to 2021 while the concept of PCK has been more investigated as the core focus of quality of education. The document type was selected on peer reviewed journal articles as well as the book chapter if that were relevant to make reviews more comprehensive (Chapman, 2021). The subject focused were Education Educational Research, Psychology Educational, and Social Science Interdisciplinary that are written in English. After this refinement, it resulted 34 articles. Then the author read each title and checked keywords to ensure that only relevant articles were selected. For instance, articles that had key terms such as technological pedagogical content knowledge were excluded. In this regard, the analysis of conceptualization and the examination of PCK outside the field of science education were diminished from the selection. There were 15 papers on Web of science have been selected.

On ERIC, the author typed the keywords on search and tick on full text available option. The refinement scoped on publication date (last 20 years), descriptor (pedagogical content knowledge), education level (preschool up to secondary education), location (select all countries which is available), and it appeared 500 articles. Based on the inclusion procedure and filtering out the irrelevant papers that were out of the scope of the study, there remained 11 papers on ERIC. Totally from both data bases, it resulted 26 papers for further analysis.

The papers were analyzed using within-case analysis (Miles, M. B., & Huberman, 1994) of each of the 26 research papers. The article was a unit of analysis. Each article paper was summarized in a category theme regarding two focuses: the research questions and the PCK assessment tool. These two focuses were linked to the research question of this review study respectively. The author did a horizontal analysis (cross-case analysis) by shifting the unit of analysis from each article to the category theme. The author finalized the themes of research questions and the description of strengths and weaknesses of the PCK assessment tool from the horizontal analysis.

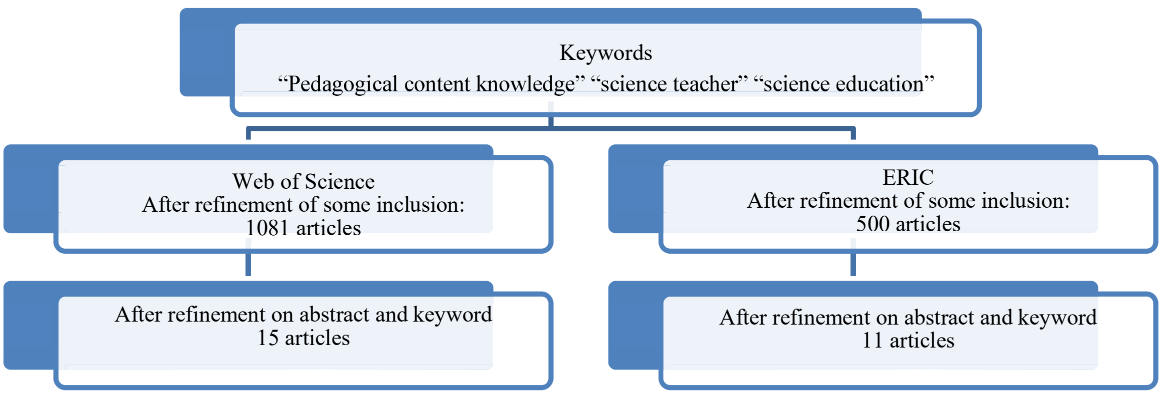

Figure 2: The procedure and criteria for selecting the reviewed articles

Source: Author’s design

3. Results and Findings

3.1 PCK Research question themes

The result in part 1 offered the findings of the various aspects of science teachers’ PCK from the snapshot of 26 reviewed articles to the research question “what themes of research questions can be generated from the reviewed articles?”. The description of this part started with a summary of the country and focused on each study and was followed by the findings of PCK themes and wrapped up with the quantitative results of the frequency of PCK themes. The studies of teachers’ PCK mostly were conducted in developed countries such as the USA, Germany, Netherlands, and Australia, while the developing countries still have fewer studies of teachers’ PCK compared to the developed countries as indicated in **Table 1** below.

Table 1: *List of countries and subjects specified in the review articles*

N^0	Country of conducting the study	Focused subjects	Authors/year
1	South Africa	Chemistry	Rollnick & Mavhunga, 2014
2	Germany	Biology-Physics	Kratz & Schaal, 2015
3	USA	Biology	Park et al., 2018
4	Germany	Biology	Großschedl et al., 2019
5	Thailand	Biology	Chapoo et al., 2014
6	Thailand	Physics	Chantaranima & Yuenyong, 2014
7	Sweden	Chemistry	Drechsler & Van Driel, 2008
8	Colombia	Physics	Melo et al., 2020
9	Netherland	Chemistry	Van Driel et al., 2002
10	USA	Chemistry	Hanuscin et al., 2018
11	Turkey	Chemistry	Abadan & Oner, 2014
12	Turkey	Chemistry	Bektas et al., 2013
13	Turkey	Chemistry	Usak et al., 2011
14	South Africa	Biology	Mthethwa-Kunene et al., 2015
15	Turkey	Science	Karamustafaoğlu et al., 2018
16	Germany	Science	Van Dijk & Kattmann, 2007
17	USA	Science	Suh & Park, 2017
18	Malaysia	Science	Halim et al., 2010
19	Thailand	Biology	Chapoo et al., 2014a
20	Turkey	Chemistry	Aydeniz & Kirbulut, 2014
21	Australia	Science	Loughran et al., 2008
22	Germany	Physics	Kirschner et al., 2016
23	USA	Earth Science	Campbell et al., 2017
24	Turkey	Chemistry	Usak, Ozden, & Eilks, 2011
25	Germany	Biology	Jüttner & Neuhaus, 2012
26	USA	Biology	Jüttner et al., 2013

Source: Author's analysis

To look in-depth at the reviewed studies above, the analysis of each research question has been conducted. Each research question is guiding the research and seeks answers to the objectives of the study (Creswell & Creswell, 2018). Among 26 reviewed articles, there were 48 research questions, and on average there were 1 to 2 questions in each article. The research questions were synthesized into four common themes: 1) measuring the science teachers' PCK, 2) Developing a PCK assessment tool, 3) identifying how science teachers' PCK develops, and 4) identifying factors that influence science teachers' PCK. Each theme was determined based on the keywords in each question and grouped into the theme. **Table 2** shows all the research questions and the targeted sample from the review articles

Table 2: *A list of research questions from reviewed articles*

Study	Research questions/objectives	Number of Respondents
1	(1) What is the quality of the content knowledge and topic-specific pedagogical content knowledge on this topic? (2) How do the CK and PCK relate to each other?	64 In-service Chemistry teachers (secondary level)
2	(1) How can we develop and validate the tools for assessing teachers' CK and PCK in the domain of Biology and Physics?	72 Pre-service science teachers (primary level)
3	(1) How can we develop and validate the measures of PCK?	85 In-service science teachers (secondary level)
4	(1) How can we validate the instrument for assessing secondary school pre-service biology teachers' PCK?	65 German pre-service and n = 35 German in-service biology teachers.
5	(1) What are the understandings and practices of the biology teacher's PCK? (2) Did the content of CoRe reflect the components of PCK as identified by Magnusson et al. (1999)?	1 In-service Biology teacher (secondary level)
6	(1) What are the elements of PCK which can be revealed from the context of a 5E stages approach to teaching?	1 In-service Physics teacher (secondary level)
7	(1) What is the content of teachers' Pedagogical Content Knowledge about students' difficulties in understanding acids and bases? (2) What is the content of teachers' PCK of teaching strategies that consider useful to help students overcome such difficulties? (3) How did the teachers perceive their PCK?	9 In-service Chemistry teachers (secondary level)
8	(1) What is the development of PCK through a physics teacher training intervention program?	1 In-service Physics teacher (secondary level)

9	(1) What development of the preservice teachers' PCK can be investigated and what is the influence of specific factors on this development?	12 Preservice Chemistry teachers
10	(1) How can we characterize elementary teachers' PCK for the matter? (2) To what extent is teachers' PCK for the matter a function of teaching experience at grade level as opposed to experience teaching overall?	38 In-service teachers (primary level)
11	(1)How do preservice chemistry teachers' PCK representations on the topic of the behavior of Gas over the semester?	2 Pre-service Chemistry teachers (secondary level)
12	All questions were asked before and after taking the course. (1)-How do pre-service chemistry teachers perceive the relationship between laws and theories, and tentativeness aspects of the Nature of Science? (2) What is the knowledge of pre-service chemistry teachers in terms of students' understanding of and difficulties in understanding the topic? (3) How do pre-service chemistry teachers teach PNM considering the knowledge of learners, instructional strategies, and assessment?	7 Pre-service Chemistry teachers (secondary level)
13	(1) What is the prospective primary school teachers' CK about states of matter? (2) What is the prospective primary school teachers' PCK?	41 Pre-service teachers (primary level)
14	(1) What content knowledge do the biology teachers have and explained in teaching genetics concepts? (2) What topic-specific instructional strategies do these teachers use? (3) What knowledge of students' misconceptions and learning difficulties, if any, did these teachers demonstrate? (4) How did these teachers develop their PCK?	4 In-service Biology teachers (secondary level)
15	(1). What are the levels of students' metacognitive awareness? (2). What are the in-class activities that are conducted by the science teacher related to the observed transformation of PCK? (3). What are the opinions of the science teacher about metacognitive awareness and PCK?	1 In-service teacher (primary level)
16	(1) What SMK do biology teachers have concerning the topic of evolution? (2) What conceptions do teachers have of students' misconceptions about evolution? (3) What conceptions do biology teachers have of subject matter representations of evolution?	In-service Biology teachers (secondary level)
17	(1) What are common patterns in the interactions among orientations and other knowledge components of PCK of the teachers?	3 In-service teachers (primary level)

	(2) How are the patterns related to their sustained implementation of the argument-based inquiry approach?	
18	(1) How effective am I as a supervisor in assisting my supervisee to be reflective? (2) How useful are the guidance and support to supervisees in assisting them to develop PCK that concerns promoting learning rather than focusing on student teachers' self-survival?	3 Pre-service science teachers (secondary level)
19	(1) What are the understandings and practices of biology teacher's PCK?	3 In-service Biology teachers (secondary level)
20	(1) What Pedagogical Content Knowledge do pre-service chemistry teachers have for teaching? (2) What potential does the STSPCK instrument have for assessing and enhancing pre-service science teachers' PCK? (3) What are the challenges associated with developing and using the STSPCK instrument?	30 Pre-service Chemistry teachers
21	(1) How does know to know about PCK influence teachers' thinking about teaching science and their PCK development?	27 Pre-service teachers
22	(1) How can we develop a test instrument (PCK test) for assessing physics teachers' professional knowledge?	186 In-service Physics teacher (secondary level)
23	(1) To what extent does the resource activation model of cognition help explain the application of orientations and topic-specific PCK by a grade 9 science teacher across topics in earth science?	1 In-service Science teacher (secondary level)
24	(1) What is the Subject Matter Knowledge of beginning student teachers? (2) What do the student teachers think concerning the teaching?	30 Pre-service Science teachers (secondary level)
25	(1) What is the student error about the reflex arc of the knee-jerk? (2) How can items for a PCK test be developed? (3) Are these PCK items reliable and valid?	5 In-service German biology teachers
26	(1) How can we develop reliable, objective, and valid instruments measuring teachers' CK and PCK?	158 In-service Biology teachers

Source: Author's analysis

*In-service teachers: refer to teachers who completed teacher training courses and became teachers at a designated school. The teacher training course lasted for one, two, or four years depending on the degree and policy of each teacher's education context. That means they are currently work as teachers.

Pre-service teachers: refer to student teachers who have not yet completed the teacher training course and are still under the training course. After completing the teacher training course, pre-service teachers will become in-service teachers.

Theme 1: Measuring the science teachers' PCK

Teacher quality is crucial for improving the quality of education. That means to say teachers play an important role in enhancing students' learning. As such, many studies have been conducted to find out what type of knowledge teachers should acquire to enhance their capacity. As already stated, Shulman (1987) initiated the PCK concept as an amalgamation of essential teacher knowledge for transforming content knowledge through teaching strategies according to subject content and context, which can ultimately ensure students' learning. However, the study of teachers' PCK seems to be placed on specific topics, for example, some studies focused on teachers' PCK for the specific topic "Acid-base", "Chemical reaction" "Photosynthesis" etc. (Drechsler & van Driel, 2008 Usak, Ozden, & Eilks, And the questions which guided in the theme "measuring the teachers' PCK" mostly aimed to measure the "quality", "understanding", "practice", "characteristics" and the "understanding of each element of PCK".

The study by Rollnick & Mavhunga, (2014) explored the Chemistry teachers' knowledge of PCK which targeted five components such as (1) knowledge of the learner, (2) knowledge of curriculum, (3) knowledge of teaching strategies, (4) orientation to teaching, and (5) difficulties when teaching the topic of "Electrochemistry". The study inquired by asking "what is the quality of teachers' PCK and how do the content knowledge and PCK relate to each other?". The findings of the quality of teachers' PCK have been explained in four levels 1) "limited", 2) "basic", 3) "developing" and 4) "exemplary" through the PCK test. Likewise, the study of Usak, Ozden, & Saglam, (2011) was guided by the question "what is the teachers' PCK on the topic of phase transaction of matter?". That focused on teachers' knowledge of student learning, knowledge of curriculum, and knowledge of representation. The teachers elaborated on the decision of teaching models or any activities for teaching the topic of Matter. Another study separated the questions by first asking "what is the knowledge of a teacher in terms of student's difficulties?" and "how do the teachers teach the subject considering the knowledge of strategies, knowledge of learners, and curriculum?" (Drechsler & van Driel, 2008) assessed Chemistry teachers' knowledge of students' difficulties and models for teaching acids and bases. The researchers asked questions like "what is the content of teachers' PCK of students' difficulties and teaching model? The assessment unearthed teachers' understanding of students' difficulties, categorized as follows: 1) students' misinterpretation of acid-base reaction equation, 2) students' preconception, 3) model confusion and 4) students' difficulties in distinguishing between explanations in a macroscopic view. The research also elaborated on the types of models that teachers had been using for teaching acids and bases. That all to investigate the teachers' understanding of students' difficulties and teaching model for teaching. To investigate a categorization of teachers' PCK, (Hanuscin et al., 2018) proposed the question "How can we characterize elementary teachers' PCK for the matter?". The study findings described the nature of PCK in different teachers and the relationship between the teachers' experiences and their PCK.

Theme 2: Developing a PCK assessment tool

PCK is known as a complex construct, hence there is no agreed-on standard tool for measuring this knowledge. However, some methods and tools for assessing PCK have been developed depending on the feasibility and means of reaching respondents. Several authors have developed a tool for assessing PCK in specific topics. In Germany, Kratz & Schaal, (2015) research posed a question: "How can they develop and validate tools for measuring CK and PCK of Biology and physics?". They adopted the existing assessment tools and added more items to the tools. The tool was constructed for the component of knowledge of students' understanding and knowledge of learning strategies, following a multi-stage development process. Park et al., (2018) addressed the same question as Kratz and Schaal but focused on the topic of photosynthesis. The development of a PCK survey test followed a few steps by first identifying the core concepts of photosynthesis and, secondly, by drafting multiple-choice test items targeting the categories of knowledge of learners and knowledge of instruction and representation. Biology experts conducted multiple checks and revisions to validate the developed items. Another study conducted in Germany by Großschedl et al., (2019) questioned "How can we validate the instrument for measuring the secondary school pre-service biology teachers' Pedagogical Content Knowledge? The researchers followed a series of three evaluations and refinement in which item analysis, scale analysis, and indicator validity were ensured for the final test items. "How can we develop a test instrument (PCK test) for assessing physics teachers' professional knowledge?"; this question inquired how they can create the test to measure the component of Physics teachers' pedagogical content knowledge.

The evaluation of the test development included the description of content validity, construct validity, and the examination of the internal structure of professional knowledge (Kirschner et al., 2016). Another question was "Are these PCK items reliable and valid for assessing the

PCK of Pupil Error?" the study by Jüttner & Neuhaus, (2012) in the USA. Thus, this one attempted to measure biology teachers' knowledge of pupils' errors on the topic of Knee-jerk. The procedure of this test development is based upon the analysis of pupils' errors from the achievement test and followed by validation (think-aloud interview) and reliability (Cronbach alpha test) Jüttner et al., (2013). "How can we develop reliable, objective, and valid instruments measuring teachers' CK and PCK?"; was not only developed for test items but also used the instrument for Biology teachers as well. The procedure of developing the test was guided by four steps 1) conceptualize the variable, 2) topic selection, 3) blueprints, and 4) structure and rubric.

Theme 3: identifying how science teachers' PCK develop

The questions in this trend aimed to explore how PCK develops over time or after the professional training program. Two directions, one as the goal of understanding how teachers' pedagogical content knowledge and another as what counts as the development of teachers' PCK. The noticeable questions were "How did the teachers perceive their PCK of teaching acids and bases develop until now; How do preservice chemistry teachers' PCK representations on the topic of the behavior of gases progress over semester-long chemistry teaching methods course; and how did these teachers develop their PCK in genetics teaching?". These three studies had similar objectives by looking at the ground how and why the teacher changes their way of teaching and the explain the satisfaction of their teaching.

Whereas the specific observation of the study by (Adadan & Oner, 2014), the study compared the teachers' knowledge of orientation to teach science, knowledge of curriculum, knowledge of students, knowledge of strategies, and knowledge of assessment over a semester. Whether to see if there is a change in their knowledge. As the main, the reflection of teachers' works corresponds to how their PCK has changed. The second direction counted on what the development of PCK has been guided by the questions such as "What is the development of PCK through a physics teacher training intervention program? Or What development of the preservice teachers' PCK can be identified?" (Melo et al., 2020; Van Driel et al., 2002). Those questions had not so different from the question of how teachers develop PCK, even though the notification of the question of "what" weighted what teachers declared, planned, and did in the class. Those development incorporated with the components of PCK.

Theme 4: identifying factors that influence science teachers' PCK

The theme of seeking the factors that may affect the teachers' pedagogical content knowledge seems to be limited. The studies mostly tested the effectiveness of training programs or the influence of teacher trainers on student teachers rather than exploring the possibility of various factors that may influence teachers' PCK. Halim et al., (2010) stated a research question "How effective of supervision on the student teachers' Pedagogical Content Knowledge? And "How useful of the guidance in supervision to develop PCK that concerns promoting learning rather than focusing on student teachers' self-survival? Testing the supervised activities if that could make any change in students' teachers' PCK. This reflection from students' teachers described the necessity of supervision that allows them to know various teaching strategies.

Among four themes of PCK research that has been conducted from 2000 up to 2021, most of the research has focused on measuring teachers' PCK rather than identifying factors affecting teachers' PCK which is illustrated in **figure 3** below.

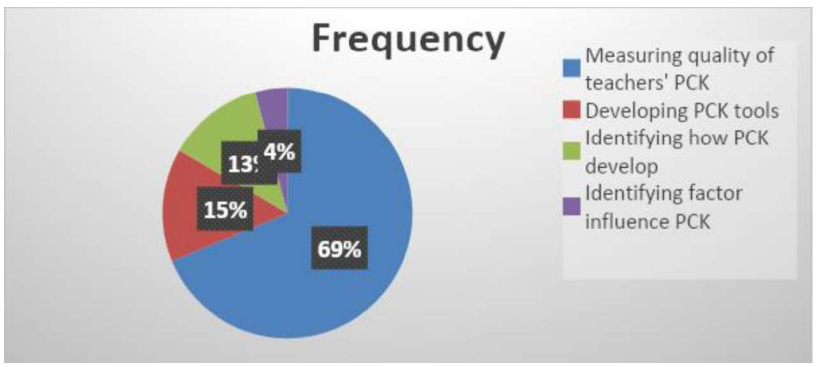

Figure 3: The frequency of PCK research themes from reviewed articles

Source: Author's analysis from review articles

3.2 PCK measurement tools

Pedagogical content knowledge has known as a complex construct in educational research. The challenge of PCK conceptualization still exists. Even though we don't reach the agreed-upon definition of the concept and the component, the investigation of each part of the PCK component serves as a mandatory assessment of the PCK construct. In science educational research, PCK has been a focal point for professionalism and teaching practices research. According to Park & Oliver, there were two dimensions of measuring PCK. First, measuring the teachers' understanding of their PCK, and second assessing their enactment in classroom practice. This perspective leads to the understanding of the nature of PCK measurement tools that are elaborated on below:

PCK survey test (Multiple choice item)

The PCK survey test was developed by Park aiming to assess Biology teachers' pedagogical content knowledge on the topic of photosynthesis. The test was developed and validated in several steps by first, identifying the core idea of Photosynthesis (what students should know when they learn the topic).

- The core ideas were analyzed based on the textbook, curriculum, teacher manual, lesson plan, and students' work sample)
- Then send the core idea to biology experienced teachers to review the importance of each idea using four points Likert scale (modification will be made if there is feedback from those teachers)
- The core ideas were grouped into a category

Second, a PCK survey (paper test) and rubric were drafted focusing on knowledge of student understanding (KSU) and knowledge of instructional strategy (KISR)

- It is a multiple-choice item grounded classroom scenario centering on the core ideas and targeted KSU and KISR.
- Checking the literature on common misconceptions and instructional strategies on that topic and start to develop an item.

*We can ask students to get more misconceptions if we can

- The test items were sent to biology teachers to make sure of content validity and then we can check Cronbach's α to make sure of internal consistency.

This type of test produces a convenient collection of large samples up to a few hundred upon the nature of the multiple-choice items test. The analysis could be done by statistical analysis which running by software, to see the mean score or level of respondents. However, the limitation of in-depth analysis on how those responses were created still needs to consider more.

Open-ended question/semi-open-ended question

This is a type of set of questions that could assess the respondent's explanation in detail. By starting with the open question related to the component of PCK, the researchers could gather ideas from the teacher through the scenario of each question and purpose. An example is a study by Rollnick & Mavhunga, (2014), who developed a topic-specific PCK test for measuring teachers' PCK by asking the teacher to state their responses in their words. Each item of the test was designed based on the component of PCK. For example, to assess the learners' prior knowledge, the test required the teachers to state if they know the students have misconceptions or not according to the written statement of students' ideas. Some test items targeted conceptual teaching strategies by asking the teacher to write the teaching methods which they think would make the students better understand the topic. The open-ended question was widely used to prompt a detail of teachers' understanding of their knowledge of teaching strategies and another part of the PCK component as well (Şahin et al., 2016; Karamustafaoğlu et al., 2018).

CoRes

This is an abbreviation of the word Content representations which is an instrument for articulating and portraying teachers' understanding of PCK. It aims to describe teachers' reasoning for how they choose the teaching strategies and how they assess their students' difficulties or misunderstandings. The content representations tool attempt to investigate the PCK of in-service or pre-service teachers and uncover most aspect of it. The contents comprised a set of questions.

"What do you intend the students to learn about this topic?
Why is it compulsory for students to learn about this?
What else do you know about this idea (that you do not intend students to know yet)?
What are the difficulties or challenges connected with teaching this topic?
What is your knowledge about students' ideas that influence your teaching of these ideas?
Are there any other factors that could affect your teaching of this topic?
What are your teaching procedures (any particular activities for engaging the idea)?
Specific ways of ascertaining students' understanding or misunderstandings around this idea include a likely range of responses" Chapoo et al., (2014).

PaP-eRs

PaP-eRs represent the term Pedagogical and Professional-experience repertoire. It relates to CoRes and aims to measure the teachers' PCK in action. Mostly, this is drawing as an interview on the specific content that asks the teachers to describe their teaching practice. The overall interview deepens on the explanation of the teacher regarding their decision on teaching activities, the reason behind why they choose those activities, and how they thought about their students understanding in that context. As can be seen, the PaP-eRs revealed the interaction between each component of PCK, by allowing the teacher to critique and reflected on how their lesson was conducted and the weakness and strengths of their action (Loughran et al., 2008).

Interview

Some studies conducted research on teachers' PCK by using the interview style. The interview questions were created based on the literature and purposed to evaluate the teachers' PCK on how to teach (Usak, Ozden, & Eilks, 2011b). Some interview styles were conducted to get insight into teachers' ideas about planning, designing, and explaining the lesson plan. However, this type of interview could be done along with classroom observation to check the consistency between the lesson plan and classroom practice. Due to the interview, the teachers required much time and let the interview environment relax, the limitation could be done only a few samples due to time-consuming. According to Drechsler & van Driel, (2008), they interviewed by following a few steps. The questions first, started by asking the teachers to present how they designed their lesson and how they have changed it over years. Second, the teachers were asked if they used the pictures or any paragraph from the textbook and why they used it. The last part of the interview questioned the teachers to discuss students' thoughts about their difficulties or any misconceptions. The last part was seeking more about how the teachers handled those students' difficulties.

Videotape/audiotaped conversation

This tool has been counted as a practical tool for measuring teachers' practice in the classroom. The study by (Melo et al., 2020) comprised several tools in one study to investigate the physics teachers in Colombian secondary schools. A videotape of the class has joined as one tool following the other tools such as an open-ended question, questionnaire, interview, and CoRe as well. The videotape gave the activities that the teacher has been performing in the class and added more essence to the other tools. The videotape has explained the teacher' tendency to classroom practice whether teacher center or pupil center. Another way of using the videotape was found in the study of (Van Driel et al., 2002), who compared the teachers' PCK over time to see how their PCK developed over time before and after the training course.

Reflection paper/field diary/lesson plan method

As there is no single rule to measure teachers' PCK, the researchers have included the investigation of lesson plan tasks (Valk & Broekman, 1999) to see the relationship between what teachers plan and what teachers do and the reason for doing it. Practical, (Hanuscin et al., 2018) have mentioned the advantage of the lesson plan task, it provided a chance for the pre-service teacher to express their opinions of teaching even though they don't have teaching experience yet. They have at least the knowledge for preparing their lesson based on their knowledge in their training course. According to the lesson plan task, the researcher could see the connection between the essential questions for the class, the objective, and how those were engaged with each other. The analysis of the lesson plan could be generated by content analysis to see the nature of PCK considering the knowledge of the learner, assessment, and curriculum. Briefly, descriptions of the tools above were reflected in two groups (Table 3) 1) as the tools that aim to measure teachers' PCK understanding according to their answers to the test and questions in the interview. Those answers were evaluated regarding the component of PCK that was targeted in each study. 2) as the group considering the enactment of teachers in their teaching practice in the classroom. Those tools highlighted what teachers do in the classroom if they were aligned with what the teacher has planned and the objective of the lesson.

Table 3: *Category of PCK measurement tools*

Group (1)	Group (2)
PCK survey test: multiple choice Open-ended question: CoRes	Lesson plan task Class observation Videotape Reflection paper/field diary PaP-eRs Interview

4. Discussions

Research question themes

Following the result of the reviewed article above, the research on teachers' pedagogical content knowledge has contributed much to understanding teachers' professional development and practice. Hence, the respondents in each study seemed to be varied and more focused on secondary in-service teachers (50%) and less on primary pre-service teachers (7.69%) as shown in figure 2 below. This notion aligned with the study of (De Quadros et al., 2011, which means that in-service teachers in secondary schools' teachers were involved with students' activities and contributed to students' learning quality a lot. Specifically, the students were first introduced to abstract concepts at the secondary level, for example, the concept of Atom and Molecule, heat, and sound. It is the critical stage of students' learning of science concepts. Research on in-service teachers reveals the practical issue and current challenge which enrich the effectiveness of improving the quality of teaching-learning.

However, the focus on in-service teachers seems to contrast with the study (Van Driel et al., 2002). Van Driel stated that the research of PCK should emphasize pre-service teachers rather than in-service teachers. Those student teachers will transform from a student-teacher stage to the teacher stage and be ready to be a teacher. Investigating and assessing their knowledge of PCK must be an important initial stage for developing their PCK and helping them to be more confident in their teaching practices.

Even though most of the research on PCK from review articles focused on in-service teachers, the empirical research on teachers' PCK in Cambodia has emphasized more on pre-service teachers and teacher trainers. The research that came from the government and international stakeholders mostly targeted teacher trainers' PCK and pre-service teachers rather than in-service teachers (Ginburg, 2010; Depaepe et al., 2015; MoEYS, 2011; Van et al, 2018). This could be the initial stage for PCK research by gathering the information of teachers' trainers or pre-service teachers first before the investigation of the in-service teacher. Through the goal of Cambodia's Education reform 2019-2023, to enhance the quality of teacher education need to be considered on teachers' education curriculum, course, content so on. However, the progress of introducing the component of PCK has not yet been fully applied to all teacher trainers. Compared to most of the research (Hanuscin et al., 2018; Park et al, 2018) on PCK in a developed country, the movement of findings information from in-service teachers is needed.

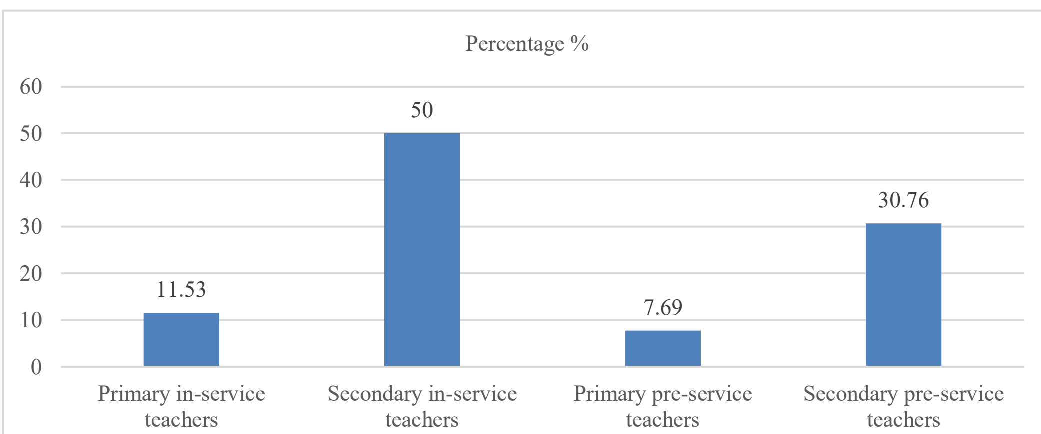

Figure 4: The percentage of respondent types in PCK research from reviewed articles

Source: Author's analysis from review articles

Some reviewed articles (Drechsler & Van Driel, 2008; Melo et al, 2020) focused on secondary in-service teachers, but they could only be assessed to a few respondents. This was due to the limitation of instruments, time constraints, and other difficulties in finance (Chantaranima & Yuenyong, 2014a; Chapoo et al., 2014; Melo et al., 2020). Another thing to be considered among PCK themes that have been found, as illustrated in Figure 1, is the research on factors affecting teachers' pedagogical content knowledge was only 4% while the research on measuring teachers' PCK reached 69%. There was a huge intention of figuring out how much teachers know how to teach and how much they understand their students while finding the reasons behind that performance was still hindered. This could be the challenge of assessing the factor contributing to the performance of PCK. That could count on the methodology, time constraints, and scope of the PCK component. The goal of improving teacher quality concerns finding a way to improve teachers' professional knowledge such as Content knowledge or pedagogical content knowledge. Currently, research on PCK has become a crucial aspect of teacher professionalism (Amanda Berry et al., 2015. However, understanding the various factors that may affect or have a relationship with teachers' knowledge is also beneficial for the sake of improving teachers' quality. Yet, the PCK literature (from review articles) seems to provide fragmented empirical evidence of factors that may affect teachers' PCK. Understanding the factor that contributes to teachers' performance or teachers' PCK, is fruitful evidence to find the practical solution for teacher education practices and professionalism.

Moreover, there were few or likely no studies on factors affecting Chemistry/Biology/Physics/Earth science at all, only studies considering the science teachers in the overall context. Noticeably, the PCK tools have developed from Biology more than Chemistry while measuring Chemistry teachers' PCK more than Biology teachers. There seems to be a mismatch between the tool created and the subjects to be investigated. Investigation of the pedagogical content knowledge of Chemistry teachers mostly tackled the topic of "Particle of Matter" whereas the other fundamental topics in Chemistry still need more attention. This notion also alerts the further development and validated tools for assessing PCK from Chemistry topics and others, to build firm fundamentals of reliable tools in each science subject. Moreover, the study of physics and Earth science teachers' PCK was less compared to other science subjects, and there is no study about Earth science teachers and how their PCK has been developed.

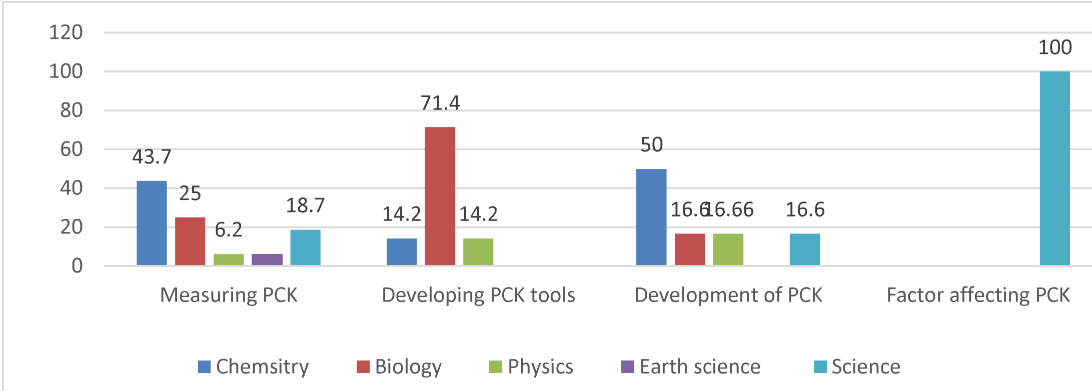

Figure 5: The percentage of research themes across science subjects from reviewed articles

Source: Author's analysis from review articles

PCK measurement tools

As Table 2 in the result section illustrates, there were a variety of tools for assessing teachers' pedagogical content knowledge. However, those tools have limitations and strengths in the measurement of the PCK construct. To compare the pedagogical content knowledge between the US and South Korean science teachers, (Park et al., 2020) conducted an online PCK survey test. The survey test assessed 166 science teachers from both countries. The test was formed of two parts, which first part was a dichotomous type, and the second part was the open-ended questions about knowledge of students' misconceptions/difficulties and knowledge of teaching strategies. This test could assess many respondents and the analysis will be done through the rubric, which was created in advance. It saved the time of analyzing even though hundreds of respondents. If the sample could represent the population, the study could make inferences about relationships among variables or may generalize to a broader population of interest (Creswell & Creswell, 2018). This is unlike interviews and class observation. Generally, the interview was conducted with targeted samples and a limited number of samples due to time constrain and other challenges such as financial support. The results could draw the themes from the interview results, and it was hard to generalize (Chantaranima & Yuenyong, 2014b; McCray & Chen, 2012).

The complexity of PCK makes it difficult to measure by using only a single instrument. Some studies suggested including several instruments; for example, the study of (Bektas et al., 2013) used open-ended questions, interviews, lesson plans, and reflection papers to survey teachers' PCK. Each tool has a different function, but the main target is to gain more understanding of teachers' PCK. In that way, the open-ended questions were designed to determine the targeted respondents;' understanding of the specific topic, followed by interviews to validate the written responses. This interview technique is followed by most research on PCK in Cambodia due to the challenge of mobilization and efficiency, which draw the findings from teachers' interviews (Ngo, 2013). Lesson plans were used to gain insight into the consistency between what the teachers plan and what they practice in the class. To understand more about how the teacher explains their teaching strategies and how to reach the goal of the lesson. To some extent, the decision of choosing PCK assessment could vary based on the resource of mobilization, efficiency, economics, and potentiality in education reform of selecting the assessment tools for the research study.

5. Conclusion

This review article has addressed some research themes on PCK for science teachers. The article has specifically synthesized what is known about measuring science teachers' PCK, how science teachers' PCK develops, the development of PCK assessment tools, and factors that affect the development of science teachers' PCK. This synthesized knowledge base can be a starting point for researchers, especially those focusing on science education development in the context of the Sustainable Development Goals (SDG 4) which highlight the significance of Science, Technology, Engineering, and Mathematics (STEM) subjects. For instance, the review findings can create a basis for further investigation of teachers' knowledge of other components apart from knowledge of students and teaching strategies that seem to have been the focus of most of the papers reviewed in this article. Second, this article has suggested variations in terms of study participants, country, and science subjects. Most of the reviewed papers focused on secondary science teachers more than primary science teachers, and PCK assessment tests were mostly validated and developed in specific countries such as the USA, Korea, and Germany. This means there is a dearth of similar research in developing countries that are also striving to improve science education through teacher quality. Last but not least, to promote excellent teaching practice, the connection between the gap in the literature and the current situation of PCK in each country, especially the evaluation of what teachers know and what teacher is doing could be a solid base for further studies.

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