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How Physics Teachers' Pedagogical Content Knowledge is Captured: A Literature Review

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Abstract: *We conducted a systematic literature review to find out how physics teachers' PCK has been captured over the 10 years. Following identification and screening process using PRISMA flowchart method, we found 29 articles and conference proceedings are eligible. Three instruments often used by researchers to capture physics teachers' PCK are interview guidelines, CoRes and questionnaires. We explore the impact of physics teachers' PCK influences physics learning for students, we need to see teachers' enacted PCK in the classroom, observation sheet or learning video assessment sheet is required. Among factors that affect physics teachers' PCK is teacher development program. Things that should be considered in teacher's PCK development program are phases when teachers develop lesson plans (development phase) and phases when teachers perform the lessons (class enactment phase). The connection between capture physics teachers' PCK, correlation between physics teachers' PCK on students' learning, and physics teachers' PCK development program were discussed.*

Keywords: *Literature review, instruments of physics, teacher's PCK*

Bagaimana Pengetahuan Konten Pedagogis Guru Fisika Dipotret: Studi Literatur

Abstrak: Kami melakukan systematic literature review untuk melihat bagaimana PCK pada guru fisika diukur selama 10 tahun terakhir. Setelah proses identifikasi dan penyaringan dengan menggunakan metode PRISMA *flowchart*, kami menemukan 29 artikel dan prosiding konferensi yang memenuhi syarat. Hasilnya adalah tiga instrumen yang sering digunakan oleh para peneliti untuk memotret PCK guru fisika adalah pedoman wawancara, CoRes, dan kuesioner. Kami mengeksplor sejauh mana PCK guru fisika mempengaruhi pembelajaran fisika ke siswa, kami perlu melihat PCK guru yang diberlakukan di kelas, lembar observasi atau lembar penilaian video pembelajaran diperlukan. Salah satu faktor yang mempengaruhi PCK guru fisika adalah program pengembangan guru. Hal-hal yang perlu dipertimbangkan dalam program pengembangan PCK guru adalah fase ketika guru mengembangkan rencana pembelajaran (fase pengembangan) dan fase ketika guru melaksanakan pembelajaran (fase pelaksanaan di kelas). Adapun hubungan antara cara memotret PCK guru fisika, hubungan PCK guru fisika dengan pembelajaran pada siswa dan program pengembangan PCK guru fisika didiskusikan.

Kata kunci: Instrumen fisika, PCK guru fisika, tinjauan literatur

INTRODUCTION

Pedagogical Content Knowledge or also known as PCK is a combination of pedagogical knowledge (PK) and content knowledge (CK). PCK was first introduced by (Shulman, 1987). Many experts define the components of PCK. Following Shulman, many education experts tried to develop the PCK framework, one of the most well-known among them is Magnusson. Magnusson is one of the figures defining PCK as the transformation of several knowledge types for teaching (including subject matter knowledge) and it represents a unique domain of teacher knowledge (Magnusson et al., 2002). PCK according to Magnusson consists into four components, such as: (a) knowledge about the curriculum, (b) knowledge about students' understanding of science, (c) knowledge about learning strategies, (d) knowledge about assessment (Magnusson et al., 2002). Those four components are important as a teacher's foundation for learning.

In teaching, CK and PK are not enough. Teachers of specific subjects including physics teachers should have specific understanding and skills that integrate their knowledge of the content of these subjects and students' learning of the content, that's the difference between a teacher's science knowledge and a scientist's knowledge (Etkina, 2010). The function of PCK owned by teachers is to mediate Content Knowledge owned by teachers in explaining concepts to students (Kulgemeyer & Riese, 2018). Research proves that students' concept mastery is influenced by teachers' PCK (Puspitaningtyas & Purwaningsih, 2021). In addition, there are also studies that assume that teacher PCK can positively predict student achievement (Keller et al., 2017). So it can be said that teacher PCK is very important in teaching students in the classroom.

Since PCK is considered as an essential knowledge in teacher professionalism. There have been a lot of research on PCK in physics teachers. PCK can be captured in various fields. Some have linked CK with PCK possessed by teachers (Neumann et al., 2019); Kulgemeyer & Riese, 2018), investigating one of the PCK components (Maries & Singh, 2016; Karim et al., 2018), looking into the relationship between teachers' PCK and student learning (Keller et al., 2017; Melo et al., 2017), PCK development program for physics teachers (Rollnick, 2017; Melo et al., 2020). All of these studies are efforts of physics educators in developing their professionalism.

With many empirical studies of PCK in physics, the literature review is contradictory to the amount of empirical studies on physics teachers' PCK. There are not too many literature reviews that discuss PCK. First, (Chan & Hume, 2019) identified the context, the main purpose of the study, the conceptualization of PCK in the study, the data sources used to investigate PCK, and the approach used to determine PCK in science teachers. Second, (Suprpto, 2019) discusses the development of research on PCK for 30 years in physics education in general. So there is still rarely a systematic review specifically on physics teachers' PCK that discusses how to capture it, how the physics teacher's PCK is related to physics learning with students and the physics teacher's PCK development program.

A comprehensive review that discusses existing findings is very important (Suryadi et al., 2023). Following the background that has been explained, the next part of the discussion consists of a review how physics teachers' PCK is captured, the relationship of physics teachers' PCK to physics learning to students and physics teachers' PCK development programs have been carried out. We believe this systematic review is important to provide insights and advance the area of professionalism in physics teachers by revealing the importance of the PCK concept and identifying the developments on physics teachers' PCK investigations.

METHOD

This study is a systematic literature review that explores how physics teachers' PCK is captured. The author reviewed research published over the 10 years (2013-2023) regarding PCK in physics teachers. Researchers used three databases in searching for articles, such as google scholar, ERIC, and springer. The keywords used to search for articles in the three databases are: ("PCK" OR "pedagogical content knowledge") AND "Physics Teacher" AND "PCK instrument".

Figure 1 shows how the article selection process using the PRISMA flowchart. The implementation of PRISMA flowcharts helps to identify key aspects of article searches and categorizes potential search terms (Wandi et al., 2023). Article selection process was conducted since November 2023- December 2023. We used Google Scholar and Eric as databases in identifying articles because they are well-known and well-established in the field of social science (Suryadi et al., 2023). When searching the Google Scholar database, researchers use Publish or Perish (PoP) to get the search results more organized. The criteria included in the review process are: 1) Open access research article, 2) Written in English, 3) Journal indexed by Scopus, 4) Focus on physics teacher's PCK, 5) Be empirical studies.

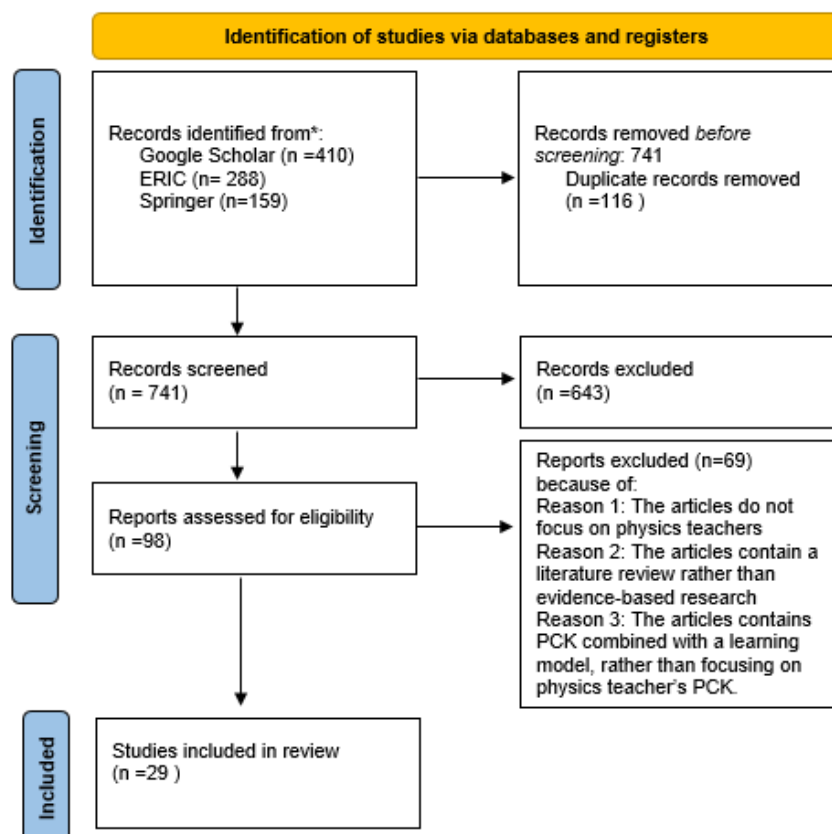


Figure 1. Article Selection Process

The articles were read one by one and then data was collected on any instruments were used in the articles. Once the data was collected, the usefulness of the instruments used in the articles was categorized. Besides the usefulness of the instrument, coding was also conducted to answer research questions related to the importance of physics teachers' PCK in physics learning and programs that support the development of physics teachers' PCK.

RESULT

There are 29 published articles from 2013-2023 that we used in this review. More about the results of the article review will be explained in the following sub-chapters.

Instruments Used In Capturing Physics Teachers' PCK

Many instruments are used to see the physics teacher's PCK. Three instruments often used by researchers to capture physics teachers' PCK are interview guidelines, CoRes (Content Representation) and questionnaires. The following is an illustration of the number of instruments used in the 29 articles described in Figure 2.

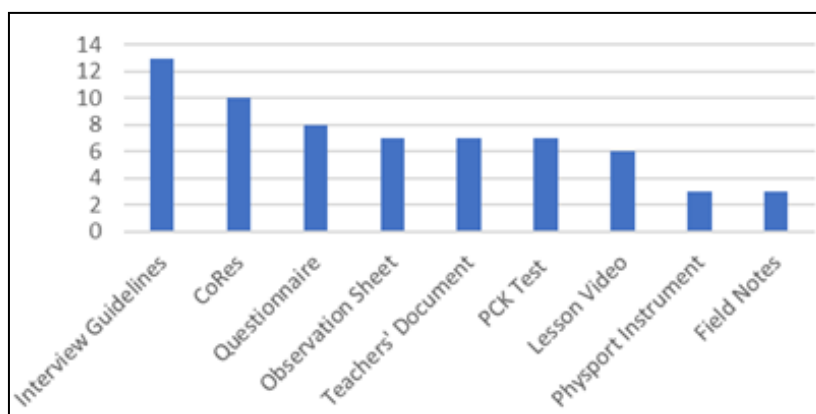


Figure 2. The Use of Instruments to Capture Physics Teachers' PCK

Interview guidelines are the most widely used instrument in capturing physics teachers' PCK. (Karim et al., 2018) conducted a think aloud interview that focused on why teaching assistants chose certain answers as the most wrong answers (including answer choices that were not common for students). This aims to deepen the extent of teaching assistants' understanding of students' difficulties in electricity and magnetism. (Qhobela & Kolitsoe Moru, 2014) used follow-up interviews to clarify and enrich and expand the results of questionnaires that had been distributed previously. Meanwhile, (Coetzee et al., 2022) conducted a two-part interview, a semi-structured interview to reflect on their learning and a video-stimulated recall interview where they viewed their learning to reflect and comment on their actions and decisions during classroom learning.

CoRes or Content Representation is a PCK instrument developed by (Loughran et al., 2004) widely used by researchers to see how teachers put content into learning. (Melo et al., 2020); (Rollnick, 2017); (Melo-Niño et al., 2017); (Coetzee et al., 2022); (Melo et al., 2017); (Mazibe et al., 2020) used CoRes as a document to see how physics teachers/prospective physics teachers present the content taught before learning begins. (Chantaranima & Yuenyong, 2014); (Ogodo, 2019) used the CoRes framework as an interview guide to deepen teachers' information in designing physics lessons. (Juhler, 2016) introduced and practiced how to make CoRes to prospective physics teachers before teaching in the field which is believed to help the development of PCK of prospective physics teachers. (Pitjeng-Mosabala & Rollnick, 2018) used CoRes before and after a 10-month intervention to see the development of physics teachers' PCK.

The questionnaires that are widely used in the articles reviewed are open-ended questionnaires. (Melo-Niño et al., 2017) used this to explore what teachers consider strategies in physics teaching and the role of planning in the teaching and learning process. This was also done by (Qhobela & Kolitsoe Moru, 2014) where 39 physics

teachers were required to give their views on how physics should be taught, some problems they faced while teaching physics, and contextual issues about teaching the environment. (Marake et al., 2022) used a closed-ended questionnaire to find out what physics teachers perceive about teaching the concept of force. The questionnaire used a 1-5 Likert scale consisting of 65 questions regarding five PCK components, such as knowledge of curriculum, knowledge of student understanding, knowledge of learning strategies, knowledge of assessment, and orientation towards science teaching.

The observation sheet aims to describe and explain how physics teachers/prospective teachers carry out activities in the classroom in accordance with what has been previously designed. (Ogodo, 2019) used the Reformed Teaching and Observation Protocol (Sawada et al., 2002) which uses a 4 Likert scale in 25 questions on 5 subscales, including learning design and implementation; content; classroom culture; communicative interaction; and propositional and procedural knowledge. Some articles used learning video instruments as well as observation sheets such as (Karal & Alev, 2016) and (Wang & Buck, 2016). Basically, their purpose can be achieved by using observation sheet or learning video, or even both. The same thing applies to field notes, which have the same purpose as observation sheets and learning videos.

Teacher documents that are widely used to examine physics teachers' PCK are lesson planning sheets. (Melo et al., 2020); (Rollnick, 2017); (Juhler, 2016) and (Karal & Alev, 2016) used planning sheets that have been made by teachers to see the development of PCK of physics teachers / prospective teachers between before and after being given an intervention. (Nurulsari et al., 2020) and (Chantaranima & Yuenyong, 2014) used lesson planning sheets to naturally capture the PCK of physics teachers/ prospective teachers without any intervention. (Jang et al., 2013) used reflection sheets for physics teacher candidates that had been made by their lecturers which aimed to provide feedback to physics teacher candidates to improve their teaching quality.

The PCK tests used by researchers are different according to the context of their research. (Liepertz & Borowski, 2019) used the ProwiN model PCK test based on (Tepner, 2012) which consists of 11 multiple choice questions and open items about physics teachers' knowledge of experiments, concepts and students' preconceptions. (Sorge et al., 2019) used a PCK test that he developed himself which consisted of 39 questions. The questions were developed based on Magnusson's PCK framework which consists of four aspects, namely knowledge of curriculum, knowledge of learning strategies, knowledge of students' understanding of certain physics topics, and knowledge of assessment. The PCK test was also used by (Schiering et al., 2023). The PCK test was used to see the level of PCK proficiency in prospective physics teachers. (Kirschner et al., 2016) also developed their own PCK test instrument which aims to assess the professional knowledge of physics teachers in the dimensions of CK, PCK, and PK. The PCK test instrument that has been developed consists of 17 questions, where almost all questions are open ended.

The Physport instrument is used by researchers to assess the PCK of teaching assistants in the knowledge aspect of identifying alternative concepts for new students and the reasons that teaching assistants use when selecting a particular wrong answer as most common incorrect.. (Karim et al., 2018) used the CSEM (The Conceptual Survey of Electricity and Magnetism) instrument, (Maries & Singh, 2013) used the TUG-K (The Test of Understanding Graphs in Kinematics) instrument, (Maries & Singh, 2016) used the FCI (Force Concept Inventory) instrument. In addition to these three instruments, the researchers also used freshmen data that had been collected over the years to identify

alternative concepts. By recognizing students' alternative ideas, a teacher can consider learning for students in the future.

Physics Teacher PCK that Influences Student Learning

We also investigated how physics teachers' PCK influences their learning from the reviewed articles. The purpose is to find out how important physics teacher's PCK is in physics learning. Research carried out by (Keller et al., 2017) found that teacher PCK affects student learning. Multi-level structural equation modeling was used to support the assumption that physics teachers' PCK positively predicts student learning outcomes. However, teacher PCK cannot predict student interest. From this, physics teachers' PCK needs to be considered in improving students' cognitive. The effect of teacher PCK on student achievement is partially mediated by cognitive activation, a feature of content-related instruction that provides cognitive challenge through teacher performance of tasks. Teachers with high levels of PCK are capable of implementing assignments of higher complexity which require higher levels of cognitive processing by students, therefore it allows them to obtain more complex and sophisticated knowledge structures as shown by higher levels of achievement. (Keller et al., 2017:601). Therefore, physics teachers' PCK has an important role in student outcomes.

Research performed by (Melo-Niño et al., 2017) indicated that teachers' self-awareness of their own PCK can lead them to be more responsive to new learning situations that occur in classroom. As in the case of teacher 1 who believes that mathematics is a tool for physics and emphasizes the use of algorithms. As a result, students' greatest difficulties in understanding the concept of electric field focused on exercises that included the use of mathematics. In this case, the possibility that teachers do not consider aspects of students' difficulties in learning may also affect students' difficulties in electric field material is. When teachers were required to identify the main conceptual difficulties of their students when learning this content, they made no reference to electric fields teach. They also did not perceive any difficulties in the future with activities they plan (Melo-Niño et al., 2017:41). Therefore, reference in teaching is very important for teachers to identify the big ideas that will be taught to students while looking for student difficulties in each of these big ideas.

Research carried out by (Ogodo, 2019) found that content knowledge alone is not enough to become a teacher. This is because to become a teacher, content knowledge must be transformed into pedagogical knowledge or in their teaching practice. Teachers who had joined this training with the aim of improving their PCK felt that their classroom activities were much more diverse than before the training. In addition, they are also more comfortable with learning and confident to implement new strategies. Teachers who were originally content-only in learning, teaching it using lectures or presentations, after their PCK developed, their classroom activities became laboratory experiment-oriented or inquiry-based.

Research carried out by (Kulgemeyer & Riese, 2018) found that the correlation of PCK with the ability to explain was significantly positive. Teachers' PCK also mediates CK owned by teachers in the ability to explain in the classroom. Besides, PCK can also increase the performance of explaining on a proper constructivist view. One of the PCK sub-aspects that affect the ability to explain physics is the knowledge sub-aspect of diagnosing prior knowledge and knowledge of identifying student misconceptions. If the performance of explaining physics increases, then the possibility that students will understand the teacher's explanation also increases.

Development of Physics Teacher PCK

The PCK development of physics teachers conducted by (Rollnick, 2017) was Training to physics teachers enrolled for part-time postgraduate qualifications for 16 weeks. The teachers and the two supervisors who supervised them in this project had weekly 3-hour group meetings over a 12-week period. In the third week, teachers and supervisors jointly developed a CoRe as prior snapshot of the PCK of the whole group. In addition, the teachers also created video recordings of their two lessons. This was done to identify the PCK categories present in the CoRes. In the sixteenth weeks, they prepared lessons on semiconductors, conducted peer-teaching and created concept maps before lessons. At the end of the project, they submitted a written report of their project for assessment.

TasS (Teachers as Students) project where data collection took place over two years (2012 and 2013). The participants were different in each year. In 2013, the intervention in this project was to introduce and use lesson study with a combination of CoRes as an effort to develop PCK in physics teacher candidates. During the intervention conducted by (Juhler, 2016), The interventions were: 1) mentor teachers and teachers on probation were introduced to the general theory of LS and CoRe. 2) They were briefed on the application of the two tools. 3) These examples were discussed in groups and plenaries. Then, the mentor teachers were given materials for the intervention. Prospective physics teacher became more focused on students' understanding of physics and understanding of assessment and less time to spent on learning strategies. The combination of LS and CoRe in this development program helped pre-service teachers to focus more intently on all the essential aspects of instructional planning from a PCK perspective. This may indicate improved opportunities for improvement.

The intervention program conducted by (Melo et al., 2020) on one teacher. The intervention program was developed according to the initial diagnosis of teacher's PCK. The study took place over two consecutive courses, before and after an intervention which was based on continuous reflection, self-regulation and metacognition. After that, the intervention program was implemented for 6 months. The intervention program includes three aspects, namely: 1) educational meetings; 2) joint analysis of classroom observations, lesson plans, CoRes, and interviews; 3) preparation of new teaching units on electric field. This was conducted to consider the appropriate environment for teachers. In addition to improving physics teachers' PCK, this program can characterize teachers' PCK.

DISCUSSION

There are various ways and methods to capture teachers' PCK. Efforts to improve the professionalism of physics teachers by measuring and exploring PCK certainly require a certain methodology and involve specific instruments as well (Suprpto, 2019). The way to capture PCK is categorized into two, i.e. reported PCK and enacted PCK (Mulhayatiah et al., 2018). Both PCK are important because the reported PCK will represent the enacted PCK in learning with students.

According the results, it can be seen that the instruments were varied across articles. Most of the instruments capture the reported teachers' PCK as well as enacted teachers' PCK. Reported PCK is the knowledge that teacher describe in written and verbal form whereas enacted PCK refers to the knowledge that teachers express while teaching (Mazibe et al., 2020). The Instruments that capture reported PCK are interview guidelines, CoRes, questionnaires, teacher documents, PCK tests and physport

instruments. Observation sheets, learning videos and field notes are the instruments used for enacted PCK.

The importance of using instruments that capture reported PCK and enacted PCK is to ensure that teachers' practice matches or almost matches with what they planned. According to (Mazibe et al., 2020), reported PCK is not always a reflection of enacted PCK during teaching. This is in line with (Barendsen & Henze, 2019) stating the the reported PCK appears to be more constructivist than the teaching practice. For this reason, PCK tests and teachers' written documents will not be sufficient to capture teachers' PCK in overall.

Physics teacher's PCK in enacting the class certainly has a big impact on physics learning in the classroom. Students who are involved will certainly be affected by the learning carried out by the teacher. In Refined Consensus Model, enacted PCK is also defined when the teacher plans for instruction and reflects on instruction and student learning outcomes through reflection-action (Park, 2019). Moreover, when the teacher is considering a proper learning to students, the teacher's PCK will also develop by itself. Focused and organized reflection on student learning appeared to be an important accelerator for PCK development (Wongsopawiro et al., 2017). However, reflection and lesson planning as a means of skill development is not enough for PCK development, there is a need to develop a better training concept than just reflection (Vogelsang et al., 2022). Therefore, teacher development programs are required to improve the quality of teachers, including teachers' PCK.

Development program such as training (physics teachers and prospective physics teachers) and courses (prospective physics teachers) are intensified to improve their PCK. Research carried out by (Yuliariatiningsih et al., 2019) showed that teachers' PCK in teaching science depends on the training program. This is also relevant with research conducted by (Karal & Alev, 2016) that teacher training was identified as a contributing factor to PCK development. The research conducted by (Yang et al., 2018) explains the effects of development programs conducted on teachers can also benefit student learning outcomes. From the results and previous research, it can be clearly seen that PCK development programs are considered very important for the development of teacher quality.

The things that should be considered in the teacher's PCK development program are phases when teachers develop lesson plans and phases when teachers perform the lessons. (Coenders & Verhoef, 2019) refers that as a development phase and a class enactment phase. They explained that in the development phase teachers discover new pedagogies, discuss them in terms of student learning, then design lesson plans, and prepare themselves for classroom. They explained that in the development stage, teachers discover new pedagogy, discuss it from the viewpoint of student learning, then design lesson plans, and prepare them for classroom, meanwhile in class enactment phase, designed lessons are applied and students are observed, then unusual findings are discussed and lesson plans are revised. Furthermore, (Sancar et al., 2021) give suggestions in their article regarding issues need to be considered for an effective Program Development process, including: attention to assessment, scale of the study, duration, comprehensiveness, dissemination, context, support and control, and collaboration.

One of the PCK development programs for prospective physics teachers must be in college is an apprenticeship by directly participating in school. Direct apprenticeship to schools will help prospective physics teachers experiencing authentic learning. Authentic learning by prospective teachers is also known as experiential learning. Kolb's

experiential learning conducted by (Suharto et al., 2022) includes four stages, including: Concrete Experience, Reflective Observation, Conceptualization, and Active Experimentation. Concrete Experience, Reflection Observation, Conceptualization, and Active Experimentation. The prospective teachers learning process becomes more meaningful and effective. Before they are assigned to schools, prospective physics teachers need to train their teaching skills to their peers first, so-called microteaching. Although microteaching is not equivalent to teaching students, there are many aspects of such practice that are very helpful such as learning to plan lessons, learning to select appropriate resources to achieve specific goals, studying research evidence regarding students' ideas, and finally learning to communicate with "potential" students and revising the plan based on questions and comments that appear while teaching (Etkina, 2010). Therefore, microteaching is useful for teachers and prospective teachers as a preparation in facing students at school.

The PCK test instruments are also important things in the teachers' PCK development program to determine the extent of the development. The information in the PCK test includes the ability of PCK in each component is useful for analyzing the strengths and weaknesses of teachers in professional competence (Maryati et al., 2019). PCK test results can't be described by teachers' CK or PK, cognitive ability, computational skills, or science knowledge (Kirschner et al., 2016). From this statement we can understand that PCK is an independent dimension and may not be well represented by other tests.

From the discussed earlier, we can see that the way to capture physics teachers' PCK depends on our purpose. By capturing reported PCK and enacted PCK by physics teachers, we can see the influences on physics learning to students. Although by reflecting on previous learning teachers' PCK can be improved, it would be better if it's assisted by a teacher development program where in the program teachers can get feedback from various parties, such as peers, supervisors, etc.

CONCLUSION

This Systematic Literature Review described how physics teachers' PCK was captured, how physics teachers' PCK influenced student learning and what PCK development programs had been carried out. Three instruments often used by researchers to capture physics teachers' PCK are interview guidelines, CoRes and questionnaires. These three instruments are the way to capture reported PCK from physics teachers. To explore how physics teachers' PCK influences physics learning for students, researchers need to see teachers' enacted PCK in the classroom, an observation sheet or learning video assessment sheet is required. Physics teachers' PCK can affect student achievement and the aspect of PCK that influences student learning is teachers' consideration of students' difficulties in specific physics content. Because of the importance of PCK, there are many PCK development programs for physics teachers. The things that should be considered in the teacher's PCK development program are phases when teachers develop lesson plans (development phase) and phases when teachers perform the lessons (class enactment phase).

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