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Original Article

The Development of a Teacher's PCK on the Use of Project-Based Learning to Teach Science

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Abstract

Teachers are increasingly expected to incorporate Project-based learning (PBL) pedagogy to teach science. While teachers' definitions and challenges in the use of PBL are widely studied, very few studies focus on the development of a teacher's knowledge of the use of PBL over multiple projects. The current research is an in-depth case study aimed at studying the development of a Finnish class teacher's knowledge on the use of PBL to teach science by using pedagogical content knowledge (PCK) as the lens to study teacher's knowledge. Data was collected in the form of interviews and classroom observation over eight weeks. Concept maps and critical incident analysis were used to analyse the data. The findings show that reflecting on student learning, use of learning materials and unexpected results in science experimentation contributed to the development of the teacher's knowledge of student understanding, assessments, science curriculum, and orientation to science teaching. The teacher's knowledge of student understanding and assessments were closely related and further led to the development of her knowledge in instructional strategies for the use of PBL to teach science.

Keywords: project-based learning, science-teaching, pedagogical content knowledge, case study, critical incident analysis

Introduction

Project-based learning (PBL) is an effective instructional method for teachers to motivate and engage students in science education (Kortam, Basheer, Hofstein, & Hugerat, 2018). Students who learn science through PBL acquire the content knowledge of science and the skills required for scientific inquiry and application of scientific knowledge (Balemen & Keskin, 2018). As a result, national curricula often require educators to incorporate hands-on learning approaches such as PBL in science teaching (e.g. EDUFI, 2016). In a PBL environment, students actively engage in knowledge construction, this in turn makes the students intrinsically motivated and engaged in learning (Bell, 2010). Studies have shown that students who learn through PBL not only fare better on tests requiring them to apply knowledge to solve problems but also report improved attitudes and motivation towards science learning (Thomas, 2000). PBL is based on 6 key principles which means that a project should begin with a driving question, engage students in collaborative activities and scientific practices, integrate many subjects, be iterative and sustained, and finally, culminate with students creating an artefact that showcases their acquired knowledge throughout the project (Krajcik, & Czerniak, 2018).

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In practice, however, teachers have varying definitions and approaches to PBL influenced by their beliefs about how effective learning is achieved, their past experiences and the type of schools they teach in (Tamim & Grant, 2013). Consequently, teachers differ in the way they plan and implement PBL (Cintang, Setyowati, Sularti & Handayani, 2017). Teachers are seen to develop their knowledge of how best to use PBL through continued practice over an extended period (Mentzer, Czerniak & Brooks, 2017). In the past, studies have focussed on how teachers develop their knowledge and skills in the use of PBL when professional development training (PDT) or a pre-planned project was provided (Mentzer et al., 2017). However, very few studies explore how teachers without such support develop their knowledge of the use of PBL (Condliffe et al., 2017; Thomas, 2000).

Pedagogical content knowledge (PCK) has been widely used to study teacher knowledge as it allows one to view teacher knowledge as influenced by various types of knowledge bases that are important for teaching (Alonzo, Berry & Nilsson, 2019). In a PBL environment, a teacher holds many responsibilities requiring them to use various types of knowledge. Therefore, PCK presents itself as a promising approach to studying teacher knowledge in the use of PBL. Additionally, teacher knowledge about PBL to teach science has not been studied using the lens of PCK. In Finland, many studies have focussed on teachers' definitions and uses of PBL (e.g. Viro, Lehtonen, Joutsenlahti & Tahvanainen, 2020). However, there is a lack of in-depth studies that seek to understand how and in what ways teachers develop their knowledge of using PBL. The current case study seeks to understand how a class teacher in Finland envisions the use of PBL to teach science, in what ways the use of PBL contributes to the teacher's PCK development, and in what ways the teacher develops a new understanding of PCK to teach science using PBL. The following section introduces the theoretical framework of this study in more detail.

Pedagogical Content Knowledge (PCK)

Shulman (1987) terms PCK as the unique knowledge possessed by a teacher that combines knowledge of the content as well as knowledge of how best the content can be taught to students in each context. Over the years, as the understanding of PCK grew, several researchers have expanded Shulman's initial conceptualisation. Park and Oliver (2008), for example, propose a hexagonal model of PCK specific to science teaching (see Figure 1). The six components interact with, influence each other, and provide a comprehensive overview of the knowledge and skill required of teachers. While three components focus on science as a school subject (OTS, KSC, KIS/R), the other components draw attention to the knowledge teachers need in relation to students and student knowledge (KSU, KA), as well as the teacher self-efficacy (TE), that is what teachers can do with the knowledge they have. Although efficacy relates to teacher beliefs, Park and Oliver (2008) view it as a component of knowledge due to the important role it plays in transferring a teacher's understanding to enactment and vice versa.

Recently researchers have come to a consensus that PCK exists in three levels: collective, personal, and enacted (Carlson & Daehler, 2019). PCK at the collective level refers to the knowledge of the domain or subject available for everyone to use. PCK at the personal level is the personalised knowledge that the teacher possesses because of their unique experiences and is readily available for the teacher to use. PCK at the enacted level, or PCK-in-action, is the PCK that is generated by drawing on personal PCK during teaching activities such as planning, teaching, and reflection. These three realms are said to interact with each other where PCK from one level can be transformed to PCK in the other levels. PCK at the enacted level and the personal level are said to interact more closely where personal PCK provides the base for the generation of enacted PCK, and enacted PCK further contributes to the development of personal PCK making it available to be used in the future (Behling, Förtsch & Neuhaus, 2022). In their research, Park and Oliver (2008) note that reflection-in-action and reflection-on-action enable the transformation of enacted PCK to personal PCK.

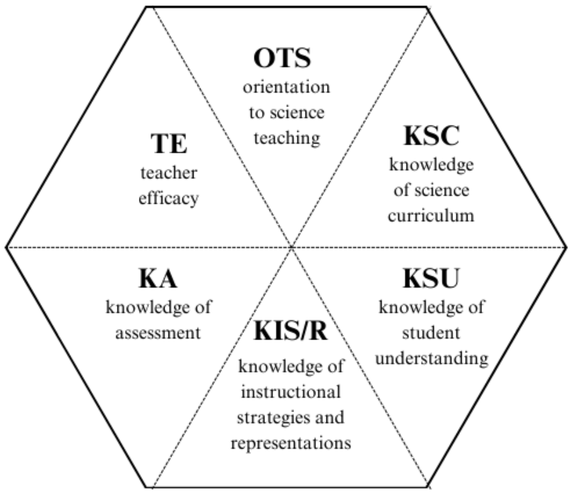

Figure 1. Hexagonal model of the components of PCK based on Park & Oliver (2008)

Shulman states that an act of reasoning, termed as 'pedagogical reasoning', always entails a teacher's decisions and actions (Shulman, 1987). Loughran (2019) substantiates that by making clear the purpose and thinking process behind a teacher's decision and action, pedagogical reasoning can make explicit the teacher's knowledge that underpins the teacher's decisions and actions. Therefore, pedagogical reasoning can make explicit a teacher's knowledge in ways that may not be obvious in their enactments. Moreover, through pedagogical reasoning teachers can reflect on their enacted PCK, to form new personal PCK, or knowledge for future use (Alonzo, Berry & Nilsson, 2019). In this study, the teacher's pedagogical reasoning is used as a filter through which the teacher's PCK development is identified and substantiated.

Teachers' reflection on student learning and understanding and teachers' orientation towards science learning stand out as key factors that inform PCK development. Teachers' identification and reflection on students' misconceptions regarding a specific science topic can significantly contribute to the development of their PCK in further planning and teaching that topic (Park & Oliver, 2008). Nilsson and Vikström (2015) also found that teachers' reflection on student learning of a specific science topic after teaching brought about changes in the way the teachers identify and organise the content. The teachers who reflected on student learning during teaching were able to proactively select and apply instructional strategies to promote student learning (Wongsopawiro, Zwart & van Driel, 2017). However, a teacher's subject matter knowledge as well as knowledge of students' understanding plays an important role in determining how well teachers can change and adapt instructional strategies on the spot and whether these instructional strategies are efficient (Chan & Yung, 2015). A teacher's knowledge of student understanding of a specific science topic before teaching influences their choice of instructional strategies to teach the topic (Bayram et al., 2019). In the use of innovative pedagogies, teachers' orientation to science learning influenced how they viewed student understanding which further influenced their choice of instructional strategies to teach science (Suh & Park, 2017). Additionally, teachers' past experiences informed how they planned to teach a science topic never taught before, and this further informed their PCK development (Chan & Yung, 2018).

In addition to teacher reflection, research suggests that critical incidents provide valuable opportunities to examine the development of a teacher's PCK (e.g. Hanuschin, 2013). In the critical incident approach, significant teaching moments are selected, and teachers are asked to share their thought processes and reasoning behind their response to the critical incident (De Jong, 2009). By doing so, teachers can make explicit their PCK in action. Additionally, Shulman (2015) specifies that PCK is dynamic and shows up in the process a teacher employs in reaction to particularly challenging situations during teaching. The role of a teacher in a PBL environment extends beyond simply ‘teaching’ science; to guiding students in constructing their knowledge and applying it to solve real-life, meaningful problems. Embracing this new form of teaching naturally leads a teacher to encounter various novel or unexpected situations. The critical incident approach provides a highly suitable way to study a teacher's development of PCK in the context of PBL. The study reported here draws on both critical incidents and teacher reflection to examine the development of a teacher’s PCK in PBL as required by the Finnish curriculum for primary education. The research questions underpinning the study are:

1. How did the teacher envision the use of PBL to teach science?
2. In what ways did the use of PBL contribute to the teacher’s PCK development?
3. In what ways did the teacher form new understandings of PCK to teach science using PBL?

Methodology

Educational Context

In Finland, class teachers hold a Master of Education with 60 credits in multidisciplinary subject pedagogy, whereas subject teachers hold a master’s degree in their subject with a minimum of 60 credits in pedagogy studies. Environmental Science (ENS) is part of the curriculum for students in grades 1-6 and includes Biology, Physics, Chemistry, Geography, and Health Education, with a focus on sustainable development (EDUFI, 2016). Students’ ability to carry out research projects is described to be essential for the achievement of ENS objectives, and teachers are expected to conduct at least one project with the students during an academic year (EDUFI, 2016). Project themes are sometimes named in the local curricula however, teachers are not provided with a mandate to follow a specific PBL framework to conduct the projects. Among Finnish students who report having participated in some kind of experimental work in science, only 21,6 % report having ever designed their own investigation (Lehtinen & Nissinen, 2018), suggesting the prevalence of structured and teacher-led inquiry in these projects.

Studies conducted in Finland on teachers’ use of PBL rely on surveys and teacher self-reports, offering extensive information about how teachers use PBL, and challenges they face. Collaboration, creation of artefacts, use of technology, problem-centredness, and scientific practices were key elements of the teachers’ use of PBL, however, teachers primarily used PBL to teach soft skills, and artefacts created by students were outcomes of discrete activities that were not tied together in a way that answered a central driving question (Markula & Aksela, 2022). Time management, lack of resources and a lack of teachers’ skills related to the use of PBL were stated as the pressing challenges hindering the teachers’ use of PBL (Haatainen & Aksela, 2021; Viro et al., 2020). By using an in-depth case study approach to investigate the development of a teacher’s knowledge of the use of PBL, the current study adds fresh insight to the existing literature on PBL in Finland. The following section further explains the design of the study.

The Case Study

With special emphasis on depth of understanding a teacher’s PBL realisation, the present study is a single instrumental case study of a class teacher in a Finnish primary school who used PBL to teach science. The specific case was chosen due to the teacher’s motivation towards using the PBL pedagogy to teach science. As a class teacher, she taught Finnish, English, Maths, ENS, History, and Arts. The projects she conducted were for ENS with students between the ages of 10 and 12. The two projects were conducted on the topics of water surface tension (WST) and electricity (see Figure 2). The WST project lasted for 3 weeks, while the electricity project extended over 5 weeks, with project classes held once a week for a total of eight weeks.

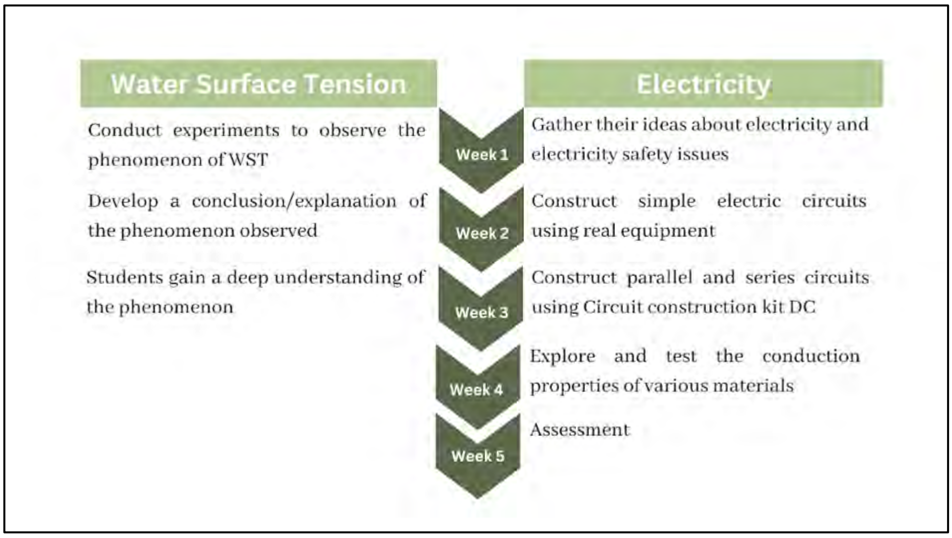

Figure 2. The Project Timeline

The WST project began by having the students perform experiments where they dropped things such as peppers and paper clips into water to observe what happened. While doing this, they noted their observations and discussed the possible explanations for the phenomenon. Next, the students read the explanations given by peers and voted for the most plausible explanation. On the final day, the teacher explained the concepts of WST to the students and then helped the students make connections between the concept of WST and the experiments they had conducted.

The electricity project started with students gathering their prior knowledge on electricity. Next, the students constructed real circuits. While constructing the circuits the students noted down the components used and the method followed. Next, the students learned about electrical symbols for the components in a circuit. Then, they proceeded to construct a series and parallel circuit using the Circuit Construction Kit (PhET, n.d.). Then, the students planned and executed investigations to check the conduction properties of materials such as paper and foil. Finally, the students had an assessment that assessed everything they learned through the Electricity project.

Data Collection

The timeline for the study is illustrated in Figure 3. Interviews and classroom observations were the primary data sources. The teacher also shared her plans and the investigation sheets which were used as supplementary data to indicate when and how the teacher altered her plans during the project. Ethical considerations for the study were considered in relation to the Finnish National Board on Research Integrity TENK's (2019) guidelines for ethical research. The teacher was informed about the purpose of the research, and the plan for data collection, data storage, timeline, and participant rights. The research proceeded after receiving signed consent from the teacher and student guardians were informed of the researcher's presence in the classroom.

Two teacher interviews were conducted, Interview 1 (I1) was before, and Interview 2 (I2) was after the projects. The first interview was unstructured aimed to provide a space for the teacher to share her existing reflections about PBL in science. The second interview was structured and followed a stimulated recall interview (SRI) approach (See Appendix). The observations focused on the enactment of PBL. The researcher (first author) was also the observer who collected the data. The observer took on the role of a silent observer with minimal interaction with the students. The events that occurred in the lessons were written down sequentially in a notebook.

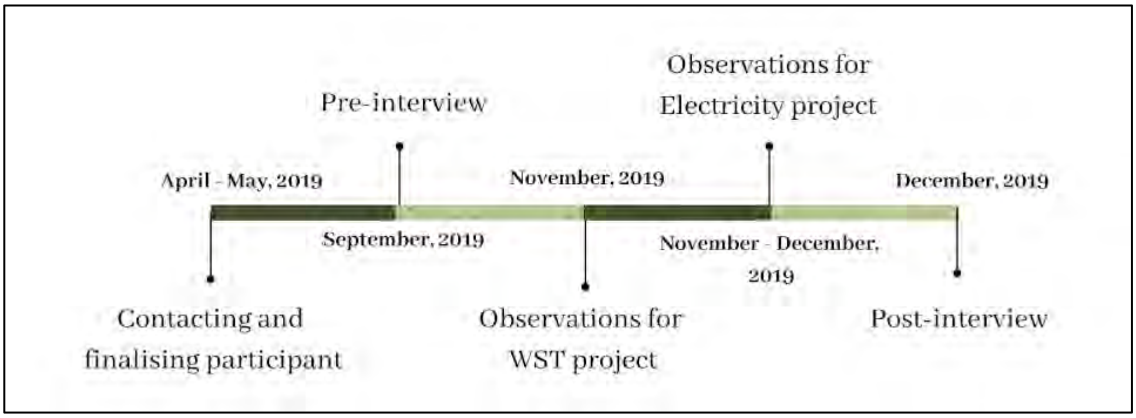

Figure 3. Timeline of the study

Data Analysis

The data analysis began with the careful organisation of the dataset and transcribing the first interview. This interview provided the starting point for the teacher's PCK prior to the two science projects and the frame for what was to be enacted in the classroom. The observations were also supported by, but not limited to, the insights from the first interview, for example, how the teacher planned to involve the students in project activities. The critical incidents collected during the observations were important material for the second, focused interview. Once the two projects were complete and the second interview had been transcribed, the analysis involved placing insights from the two interviews side-by-side, as outlined below, and comparing insights from the interviews with the critical incidents identified through the classroom observations.

The initial analysis of the interview transcripts involved drawing concept maps using the tool Cmap. The first step in the process included data reduction. During this step, key phrases from the transcript were transferred to an Excel sheet and then to the Cmap tool. Next, clusters of phrases representing the same concept were identified and grouped. Concept maps offered an efficient way to visibly display the data and identify interconnections. The concepts in the maps were aspects of PBL that the teacher regarded as important. Examples of such concepts are Group work, Goals in projects, and Assessments.

A critical incident analysis approach was taken to analyse the classroom observation notes. As an analysis method, critical incident analysis can be used flexibly and adaptably, and the events that are considered critical can differ based on the research questions pursued (Gremler, 2015). In this study, two types of incidents were considered critical: 1. Teacher actions that indicate a deviation from the initial plan, 2. Teacher actions in response to an uncertain event during teaching. Three significant CIs were chosen for further probing. For ease of representation, each action recorded in the observation notes was called a teaching moment (TM). A code was given to every teaching moment. Further, teaching moments occurring sequentially that corresponded to the same specific goal were grouped as a teaching sequence and descriptive notes were added to explain these sequences. For example, in CI 3 "Whole group lesson", the teaching sequence involves moments TM1 to TM19 when the teacher recaps what the students learnt in the previous class. These actions were grouped, and a descriptive note was added for the sequence (see Table 1). The critical incidents were presented to the teacher for further probing.

Findings

The findings begin by outlining the teacher's vision of PBL in science which includes teacher and student roles based on both interviews. The second section focuses on learning materials in PBL and the final section addresses how failed experiments prompted the teacher to reform her PCK.

Teacher's vision of the use of PBL to teach science

At the core of her understanding of PBL, the teacher saw PBL as a process that would enable students to construct knowledge of scientific phenomena. The teacher saw herself as a guide in PBL and wanted to be able to direct students to focus on the right goals and resources available. She also saw learning materials as a tool that would allow her to act as a guide and not the source of information in the projects. This vision acted as the purpose of using PBL and determined how the teacher planned PBL and the pedagogical tools she intended to use as part of PBL.

The teacher referred to and used several pedagogical tools as part of PBL which aligned with understanding of PBL in science. The teacher wanted the students to learn about scientific phenomena by conducting *scientific investigations* (SI). During SIs, the students were to observe the phenomenon, predict and note down results, and arrive at a conclusion/reason. Worksheets were provided that took the students through a step-by-step process of conducting an SI. To enable *self-guided learning*, the teacher provided students with information booklets. Group work and *social skills* were also seen as an important part of PBL. Through group work, the teacher expected the students to discuss and share ideas with their peers to be able to build new understanding and to consider different perspectives. The teacher saw projects as an opportunity for students to be able to choose how they want to display what they have learnt although this was not evidenced during this study.

The kind of questions that the teacher ponders over pre- and post-project differs. Pre-project, the teacher wonders about how to guide the students generally in constructing their knowledge. During and after the projects, the teacher wonders what the students are learning, and how much support the students need in learning specific scientific concepts. The CI "Whole group lesson" presented in Table 1, for example, shows how this need-to-know-what students are learning manifested in action during the project. On Day 4 of the Electricity Project, the teacher altered the course of the project to conduct a whole group lesson on the topic series and parallel circuits to know what the students have learnt and to correct student misconceptions. The teacher adds that the learning materials were difficult for the students to follow and therefore, she needed to conduct this whole group lesson to take the 'learning process forward' (Teacher, I2).

Table 1.
Critical incident 3: "Whole group lesson"

TMs	Descriptive notes of teaching sequences
TM1-TM19	General discussion and recap about what the students learned in the previous class.
TM20-TM21	Teacher explains to the students what they will be doing in the class.
TM28-TM32	The teacher goes over what series and parallel circuits are.
TM33-TM64	The teacher plays the video on series and parallel circuits.
TM65	Teacher hands the booklet and worksheet they have been using to learn about series and parallel circuits.

As a result of not knowing what the students are learning and how much guidance they need, the teacher speaks of wanting to have more 'control' in projects in the future. Control here refers to conducting check-ups of the worksheets to know what the students are learning and provide timely feedback. However, while doing this, the teacher continues to want to provide the space for the students to construct their understanding.

> Teacher: *I want them to you know be able to learn something that I have not imagined. I might not be thinking outside the box sometimes so my view of thing is not the only truth. But still I need to have some check up points. Do you know what I mean?* (I2)

While the core principles regarding PBL remained constant, this finding shows that the questions the teacher ponders transform from being general before the projects to being more specific regarding students' progress in learning science concepts during and after the projects. The not-knowing of what the students are learning during the projects led the teacher to alter the instructional strategy. In interview 2 the teacher expresses a need to want to have more control over projects and in practice the teacher sought to bring in more control by checking student worksheets and providing them with timely feedback. However, despite wanting to have more control, the teacher continued to see herself as a guide and learning materials began to play an even more important role in driving the project forward.

Learning materials in PBL

The learning materials used in the projects were worksheets that helped students in conducting SI, and booklets that helped the students with conducting SI and learning new science concepts. Two major shifts occurred in the way the teacher spoke about learning materials in PBL. The first shift was regarding the role of the materials. As the excerpt indicates, the teacher initially spoke of preparing learning materials to guide the students in conducting self-guided work and scientific investigation. However, during the projects, the teacher noticed that the students were not using the worksheets during scientific investigations, and when they did, they were unable to understand how to use them. Therefore, on many occasions, the teacher repeatedly brought the students' attention back to following and completing the learning materials. As a result, completing the learning materials sometimes became the focus of the investigation. The CI "Filling the investigation worksheets" presented in Table 2 is one such example.

Teacher: *I have to plan a lot and do a lot of extra to prepare them for the self-guided work. I can't be with them all the time, that's why I need lots of guiding questions and material*. (Interview 1)

Table 2.

Critical incident 2: "Filling the investigation worksheets"

TMs	Descriptive notes of the teaching sequence
TM9 - TM12	The teacher checks on the group that was doing the pepper experiment and notices that they have not filled out the investigation worksheet yet.
TM13	The teacher informs the students that they must first write the prediction before starting the investigation.

In the post-interview, as the teacher goes over some of the completed worksheets, she notices that some student responses were not aligned with how SI needs to be done, and students were unable to arrive at accurate explanations for the observed phenomenon. Further, the teacher reflects that she should have gone through the answers the students had produced to provide individual feedback for the students. From this point onwards, the teacher spoke of learning materials as a tool that would provide more information about student progress and support requirements.

Teacher: *Maybe at this point now I can see that. Maybe at this point. I should have gone them [Investigation worksheets] through really carefully and then give them [students] individual feedback. But I don't know... it is also like part of learning process that they get to... to take the kind of testing situations by themselves. But maybe feedback would've been good to have at this point.* (Interview 2)

These findings indicate how the teacher's understanding of the role of learning materials changed throughout the project. Before the projects, learning materials were considered a tool to help students with self-guided work and SI. On many occasions during the projects, filling out the worksheets became the focus of the project. After the project, worksheets were seen as a tool to help the teacher know about the students' progress and support requirements. The second significant shift was about the reliability of learning materials.

Arriving at the 'wrong' answers

A critical incident on Day 4 of the electricity project revealed the inaccuracy of the learning materials which in turn influenced the teacher's understanding of learning materials from the internet. As elaborated in the CI 'Whole group lesson', the teacher conducted a lesson taking the students through the process of filling out the booklet that consisted of a table requiring information about the volts and amperes in a series and parallel circuit. After filling the table, the next step was to observe the pattern in the readings, and answer questions related to current and voltage in series and parallel circuits. However, at this point, the teacher noticed that the answers they have arrived at do not match the answer key. The CI presented in Table 3 elaborates on this in detail.

Table 3.
Critical incident 4: "Arriving at wrong answers"

TM number	Descriptive notes of the teaching sequences
TM130 - TM131	The teacher and students look at the table for the answer.
TM132 - TM146	The teacher figures out that the answers they got don't match the answers in the booklet's answer key.
TM135 - TM146	The teacher tries to reconstruct the circuit to get the answers that match with those given in the answer key but does not succeed.
TM147	The teacher moves on to the next experiment.

Figure 4 shows the values the teacher and students recorded together during the whole group lesson. The values recorded were accurate. Figure 5 is the answer key provided in the booklet. The answers provided in the booklet were incorrect. The teacher reflects on this incident in the post-interview by saying that she should check the materials before using them in the class.

Teacher: *That was just the point where I thought that I need to always check the answer keys, if I take any resources from the um... teaching websites, then I need to go it through with my own time before hand so I cannot use those resources anymore without any preparing time*. (Interview 2)

Number of light bulbs	Current, A		Voltage, V	
	Series	Parallel	Series	Parallel
1	12	12	120	120
2	6	24	60	
3	4	36	40	

Figure 4. The teacher's and students' answers

In response to this dilemma, the teacher seeks to take back control in the classroom working together with the whole class and afterwards reflects on the importance of being vigilant when selecting materials from online. Other critical incidents during the lessons concerned experiments conducted by students.

Series and Parallel Circuits **Answers**

1. How was the current in the series circuit affected by increasing the number of bulbs?
The current remains the same / unchanged in a series circuit.
2. How was the current in the parallel circuit affected by increasing the number of bulbs?
The current is shared between the number of branches / bulbs in the parallel circuit.

Figure 5. Questions and answers given in the booklet

'Failed' paper clip experiment

In the WST project, the teacher planned investigations for the students to observe the phenomenon of WST. One such investigation required the students drop a paperclip on water to observe what happens. According to the teacher's plan, the paper clip was supposed to float on water, and in future lessons, the teacher was going to use this observation to help students build an understanding of WST. However, on this occasion the paper clip sinks. The CI of the "Sinking paper clip" and the teacher's response are presented in Table 4.

Table 4.
Critical incident 1: "Sinking paper clip"

TM number	Descriptive notes of the teaching sequence
TM9-TM22	The students try to make the paper clip float according to their prediction but are unable to.
TM23	The teacher sees that the paper clip has sunk, and she starts to attempt to make the paper clip float.
TM24 - TM26	The paper clip sinks, the teacher reattempts to make it float, but the paperclip continues to sink.
TM28	The teacher redirects the students to focus on writing down their observations in investigation forms.

When the teacher notices the sunk paperclip, at first, she tries to make the clip float, but fails. Later, the teacher walks away and asks the students to note down whatever they observe. From this point onwards during the class, the teacher encourages students to note down in their worksheet whatever they observe. The sections below further explain how this incident depicts and influences the teacher's understanding of the nature of experimentation and topics in science.

The teacher's reaction to the CI "Sinking paper clip" in the post-interview follows the same pattern as her reaction during teaching. Initially, the teacher reveals that she felt frustration wondering whether the students would be able to learn anything from this experiment.

> Teacher: *I may be felt a bit frustrated.. like "Oh dear, now it is not working at all" like, what will they learn from this, so… I was really happy that one of them got it to float*. (Interview 2)

As the teacher continues to talk about this incident, she gradually begins to reflect on the nature of scientific experimentation. She shares that the students not getting the paperclip to float was for the best because that would allow them to see the importance of keen observation when 'doing' science.

> Teacher: *I think that it's also lucky that they didn't get it to float, like each one of them so... because they could also see that science is also like making your own experiments and then testing your hypothesis and sometimes you get some kind of results which don't, you know, give you certain expected results.* (Interview 2)

This finding shows that the teacher's initial or spontaneous reaction to the 'failed' experiment both during the experiment and post-project is that of frustration and needing to get the experiment right. However, her later reflection recognises the importance of directing students' attention to the process of scientific investigation and reflect on the nature of scientific experimentation.

The teacher's goal of conducting projects revolved around the idea of wanting students to own their process of learning. The students started by performing some observations and investigations and used an investigation form to arrive at explanations for the investigated phenomenon. However, contrary to past experiences, the teacher was not satisfied with the explanations the students arrived at in the WST and electricity projects. As the teacher reasons why, she draws on an example from her experience. In the past, she had conducted a project on the topic of Healthy Habits involving students exploration of healthy habits. For this, students planned and conducted surveys and drew accurate conclusions. The teacher concludes that the reason the students were able to arrive at the right conclusions in the previous project was because the topic was already familiar to students whereas the topic of WST and electricity were not familiar. Additionally, she refers to the topic of healthy habits as *broad* with more than one explanation being possible. The topics on WST and electricity, on the other hand, were referred as *narrow* as just one explanation was possible. The notion of a narrow topic having a single right answer that the students should arrive at perhaps explains the teacher's spontaneous reaction when the paper clip sank as her initial intention was to get the experiment right.

Teacher*: For example if I would think about this goals that would be suitable for each subject would be that if the child is able to work with a pair or a group that's quite broad goal but then specific goals would be, I know that a circuit would need a source of energy it needs something to conduct electricity and you know so that would be quite narrow aspect*. (Interview 2)

The teacher further reflects on what to do differently when teaching narrow topics in the future. To ensure that students' unfamiliarity with a topic does not act as a barrier to having them own their learning in a project involving narrow topics, the teacher talks about changing the pedagogical approach. When conducting projects on 'narrow' topics in the future, the teacher would start by having the students go over the learning materials so that they gain familiarity with the topics before conducting investigations and arriving at conclusions.

Teacher: *So maybe I would just, next time when I'm teaching electricity, I would only may be give them time to get to know the material first, or maybe we would explore first and then we would get to know the material and then the concepts would get deeper understanding and then we would go them through together with the some kind of base material but now they had to go through after exploring they have to go through the material by themselves, because I thought that it would be good to do it afterwards to kind of like get better understanding of the theory.* (Interview 2)

Additionally, because narrow topics are previously unfamiliar to the students, the teacher also mentions that it is hard to anticipate student answers. As a result, the teacher suggests introducing more check-ups of the worksheets. However, the teacher also shares that it is hard to conduct many check-ups due to limited time during the project. Therefore, the teacher suggests she conduct shorter projects as that would allow her enough time to check student work, identify misconceptions and provide feedback to guide the students in the right direction at the right time. In summary, this finding shows that the teacher sees topics in science as being divided into two categories - broad and narrow. The topics of WST and Electricity were considered narrow topics unfamiliar to the students with only one right answer. To teach such topics in the future the teacher plans to first familiarise students with the topic and conduct shorter projects with more check-ups reducing the space for uncertainty or inaccuracy and reiterating the importance of the teacher's role.

Discussion

The case study reported here focuses on a Finnish class teacher using PBL to teach the scientific concepts of WST and Electricity. The study aimed at understanding how the teacher envisioned the use of PBL, how the use of PBL contributed to her PCK development and how she develops her PCK for the use of PBL to teach science. The teacher saw PBL as a way for students to construct their knowledge with the teacher using learning materials as guides in the process. Scientific investigation, self-guided work, social skills, and multiple ways of displaying knowledge and skills were four components the teacher considered to be part of PBL. The teacher's reflection on student learning, and critical incidents with the use of learning materials and unforeseen results in science experimentation contributed to the teacher's PCK development. Figures 6 and 7 represent the map of teacher's PCK development and the connection between key triggers and the reforming of the teacher's personal PCK. The solid lines in the figures represent strong connections and the dotted lines represent possible connections.

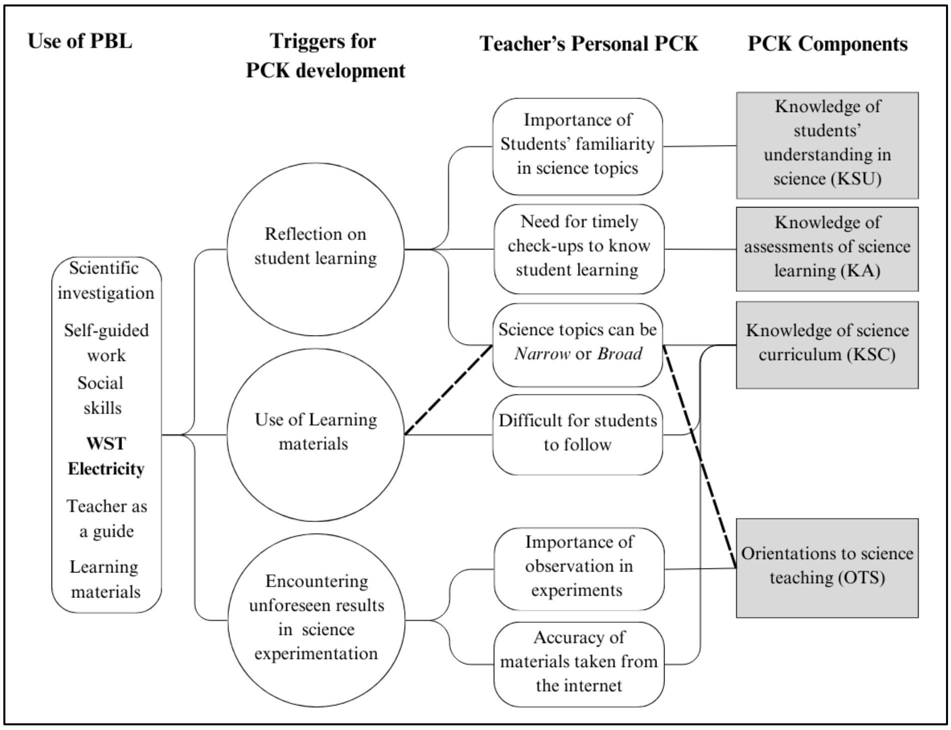

Figure 6. The development of the teacher's PCK

In line with Chan and Yung's (2018) finding, the teacher in the case study also planned the teaching of new science topics based on her prior experiences with PBL. However, not-knowing what students were learning led the teacher to realise the necessity and importance of conducting check-ups to inform her about students' understanding and support needs. This indicates a shift in the teacher's knowledge of assessments of learning science. However, the teacher's need to conduct more check-ups stems from the need to gain insight into students' understanding during PBL. Therefore, the PCK components of knowledge assessment and knowledge of students' understanding can be considered closely connected. Further, the teacher's knowledge of assessment led to the development of her knowledge of instructions strategies for teaching science using PBL (see Figure 6), with implications for her enacted PCK. This finding contrasts with that of Wongsopawiro, Zwart and van Driel (2017) where teachers' knowledge of assessment was derived from external factors such as peer discussions and literature reviews.

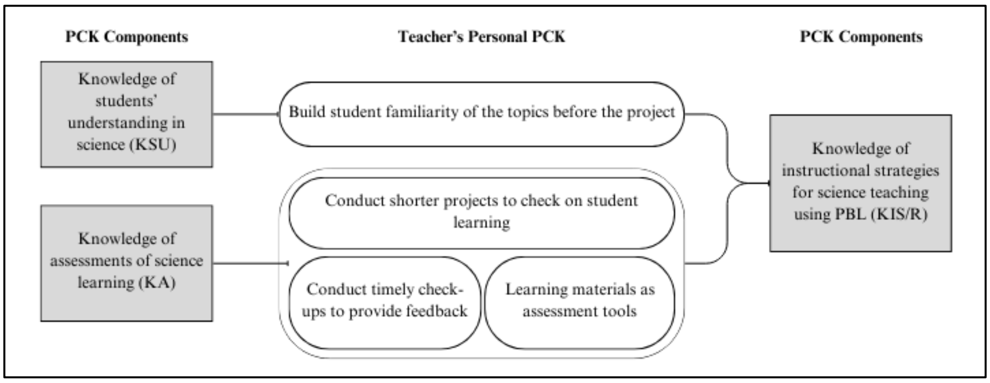

Figure 7. The development of the teacher's knowledge of instructional strategies

Nilsson and Vikstorm (2015) note that after a cycle of plan-teach-reflect, teachers identify and organise science content to better promote student learning. The teacher in the current study categorises science topics as being broad or narrow based on how familiar students are with the topics. As a result, she realises the importance of students' prior familiarity with science content when learning through PBL. In their study, Chan and Yung (2017) note that teachers who consider students' prior knowledge can foresee potential learning difficulties and plan instructional strategies accordingly. However, in the current study, the teacher was not seen to pay attention to the students' prior knowledge of WST and Electricity before the project started. Considering students' prior knowledge and familiarity with new topics shows a shift in the PCK component knowledge of students. Nevertheless, in this study as in Bayram et al's (2019) study, an increase in a teacher's knowledge of students contributes to an increase in their knowledge of instructional strategies and responses.

The categorisation of the WST and electricity projects as narrow further indicates a new understanding of the PCK component knowledge of content. The idea that some science topics are 'narrow' signifies a framework of understanding the teacher possesses about science, indicating a shift in the teacher's orientation to science teaching (Park & Oliver, 2008). Suh and Park (2017) highlight that teachers' orientation to science teaching influences how they view student learning, in turn influencing their choice of instructional strategies. Therefore, we may say that the teacher's new orientation may influence how she plans projects on 'narrow' topics in the future. It is possible that the heavy focus on following and completing the learning materials could have contributed to the teacher's categorisation of WST and electricity as narrow topics. It is also worth noting that the complexity of the learning materials could have challenged the teacher's sense of efficacy in teaching these topics. The realisation of the complexity and inaccuracy of learning materials led the teacher to reflect on the quality of curricular materials available online. While the use of curricular materials is seen to develop teachers' knowledge of instructional strategies and students' diverse needs (Bayram et al., 2019), in the current study we note that the use of curricular materials contributed to teachers' knowledge of content and potentially to the teacher's orientation to science teaching.

The contrast between the teacher's initial and later reactions to the 'failed paper clip' experiment indicates how a teacher's personal PCK does not always readily translate to enacted PCK. This finding supports that of Behling, Förtsch and Neuhaus (2022) who specify noticing and knowledge-based reasoning as a necessary filter for the transformation of personal PCK to enacted PCK. In this case study, the teacher's reflection-in-action and reflection-on-action prompted this transformation and can be said to have further strengthened the teacher's orientation to teaching science.

Conclusion

The current research shows that teachers develop their knowledge of the use of PBL over multiple projects. Identifying critical incidents during practice and probing for the teacher's pedagogical reasoning proved to be an effective way of capturing the teacher's PCK development. The in-depth case-study approach of the current research adds fresh insight to the existing literature on PBL in Finland. There is a need to make more explicit what constitutes PBL. Studies in the past have identified that teachers need resources such as problem statements and project plans to implement PBL more successfully (Viro et al., 2020). Teachers could benefit from the availability of validated PBL ideas and resources for a variety of science topics. Finally, we suggest the need for further studies that investigate teachers' enactment of PBL more closely rather than rely on teachers' self-reports.

The use of projects noted here is not representative of all projects implemented by the teacher or other teachers in the same context. This limits the generalisability of the findings and suggestions. PCK being tacit (Alonzo, Berry & Nilsson, 2019) limits the possibility of capturing a teacher's PCK entirely with just two projects. However, the use of concept maps and critical incident analysis directed our focus to the most significant components of the teacher's PCK development. A commonly stated limitation of notetaking is that the notes are considered to some extent a researcher's interpretation of reality (Gobo, 2011). To eliminate including interpretations during observations, the events that took place during the projects were organised sequentially as they happened. Any analytical reflections and interpretations in the moment were noted down separately. Learning materials stood out as significant in the development of the teacher's knowledge in current research. Future research could benefit from a deeper exploration into how curricular materials contribute to teachers' PCK development as well as the pedagogical reasoning of teachers as they negotiate ways to enable students' as independent learners in PBL.

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Appendix A

Interview 2 questions

Part 1: Project narration

- Can you describe the goals, planning and approach taken for the projects conducted?

Part 2: Reflection on critical incidents

- Can you share your experiences during the paper clip experiment?
- Can you share your experiences during the whole class lesson?

Part 3: Reflection on students' artefacts

- What do you think about students' learning during the projects? (Pictures of students work during the projects)

Part 4: Reflection on future directions with PBL

- If you were to conduct the projects again, how would you approach it?