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Technological pedagogical content knowledge of primary school science teachers during the COVID-19 in Thailand and Finland

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Abstract

Technological pedagogical content knowledge (TPACK) is important for teaching science during the COVID-19 pandemic. This paper investigates the TPACK of Finnish and Thai primary school teachers in the context of teaching science through blended learning (BL) during the COVID-19. 11 teachers from Finland and Thailand were interviewed. The interview data were examined using deductive content analysis. The analysis revealed that all teachers used educational technology in their online classes in terms of providing the lesson content, learning activities, and the students' learning assessment. Zoom and MS Teams were the tools used for online teaching in both countries. The main teaching method used in both types of instruction was experimentation. For online instruction, most teachers considered educational technology in every step of the teaching process to enhance students' learning of science as much as possible. Many types of direct and technology-mediated interaction appeared during BL, especially during online teaching, which could be designed and analyzed in the context of the TPACK model.

Keywords: blended learning, content analysis, COVID-19, primary school science teachers, technological pedagogical content knowledge

INTRODUCTION

The COVID-19 pandemic has limited educational opportunities for many students around the world at all levels, especially those with disabilities or from lower socioeconomic backgrounds. This is because many countries implemented lockdowns and other types of distancing policies to limit the spread of the infection. The pandemic has affected more than 1.7 billion learners, including 99% of students in low- and lower-middle-income countries (UNESCO, 2020; United Nations, 2020, p. 2). This has resulted in an unprecedented crisis in education and school closures across the globe. According to UNESCO (2020, p. 5), as most countries are now reopening or planning to reopen their educational institutions, it is crucial to ensure the return of all learners. Many researchers have studied the impact of COVID-19 on science education in several dimensions, such as teachers' workload, teachers' use of information and communication technology (ICT) in remote learning, and pedagogy and content adaptation. The results have shown that there are challenges in adopting pedagogy for online science learning, which guides students to make observations and investigations in line with the curriculum. However, teachers have tried to include experiments and practical activities in their lessons (Amarachukwu Nkechi et al., 2021; Chadwick & McLoughlin, 2021; Leonardi et al., 2021).

Therefore, teachers must be able to effectively use new instructional tools and methods such as digital learning tools and environments. Education Endowment Foundation (2019) has offered guidelines for supporting the use of technology in teaching and learning, supporting subject-related knowledge practices, such as inquiry in science. Reimers (2022) summarized the experiences of teaching and learning during COVID-19 in 14 countries, indicating that teachers have found it challenging to manage their instruction appropriately. In selecting suitable instruction, teachers must recognize the child's level of development, concentration, motivation, and previous knowledge and experiences in addition to the curriculum. Another challenge is how to motivate students to learn and interact with online

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Contribution to the literature

- Dimensions of TPACK: (i) using technology to teach content knowledge, (ii) using technology to ensure versatile communication, (iii) educational technology can enhance students' prior knowledge or develop new knowledge, (iv) different backgrounds of students in the classroom, and (v) different content concepts and student skill levels used for analyzing the interview of primary school science teachers in Finland and Thailand.
- The interview analysis of experienced primary teachers in Finland and Thailand was considered their science teaching and learning during the COVID-19.
- Zoom and MS Teams were the main educational technology tools for online teaching and learning in both countries which were used in a versatile way. The textbook was used as the main learning material in online and on-site teaching.

teaching. One of the most serious consequences of the COVID-19 pandemic on students' well-being is loneliness (Loades et al., 2020). Consequently, teachers need knowledge and skills to plan lessons that engage their students interactively while they learn the subject according to the curriculum. Technological pedagogical content knowledge (TPACK) was developed to describe the set of knowledge that teachers need for teaching a subject while using technology in the class. Educational technology has various meanings in the literature. Educational technology refers here to a variety of digital devices, tools, software, or applications that support learning process in a classroom (Cheung & Slavin, 2013).

TPACK combines Shulman's (1987) structure of pedagogical content knowledge (PCK), content knowledge (CK), and education technology knowledge. Johnson et al. (2016) presented common challenges faced by educators when attempting to integrate technology in the classroom and offer potential solutions to those problems. There are both internal and external challenges related to teachers' implementation of classroom technology. Blended learning (BL) is an instructional model that combines online and classroom learning activities and properly uses resources to improve students' learning outcomes and address important institutional issues (Kaur, 2013). As teachers engage in online teaching, many educational technologies have been brought into the classroom to organize the class activities and convey the content of a lesson. Accordingly, primary school teachers have had to adapt their approach to teaching rapidly with the shift to remote learning (Leonardi et al., 2021).

Since April 2021, the COVID-19 situation has been getting better in both Finland and Thailand, and teachers have used the BL approach. Therefore, **the research question** that guided this research is "how do Finnish and Thai primary teachers employ TPACK in blended science teaching situations during the COVID-19?" and **the objective of the research** is to investigate the TPACK of Finnish and Thai primary school teachers in the context of teaching science. Therefore, TPACK and BL are introduced in the next chapters. This introduction will be utilized in the development of an interview protocol for teachers. Finland and Thailand were selected for the study because the COVID-19 related policy has been rather successful in both countries, and students have participated in distance teaching and BL.

Technological Pedagogical Content Knowledge

For almost 16 years, TPACK has been used as a conceptual framework to describe the knowledge base teachers must have to effectively teach with technology (Mishra & Koehler, 2006). TPACK combines three main teacher knowledge types (content, pedagogy, and technology). TPACK's main idea is stated, as follows:

> The basis of good teaching with technology and requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face (Mishra & Koehler, 2006, p. 1028-1029).

However, the original definition of TPACK is based on a teacher-centered view of teaching and learning. Here, we emphasize student collaboration, working in small groups, such as in break-out rooms, and student-student interaction in addition to teacher-student interaction. Technology can support students' in classroom teaching and enable varied activities catering to the needs of every student. The term BL is applied to teaching and learning that uses a variety of 'the most effective instructional approaches supported to achieve learning objectives' (Wilson & Smilanrich, 2005, p. 3). Likewise, Harper (2018, p. 214) stated that 'technology promoted collaboration between teachers and students during learning activities, and teachers who used technology leveraged it to maximize their uses of strategies aimed at facilitating learning and promoting students' exploration of content'. During the COVID-19 pandemic, BL has supported the integration of face-to-face and online instruction (Graham, 2013).

From the point of view of implementing teaching and learning with technology, teachers should understand

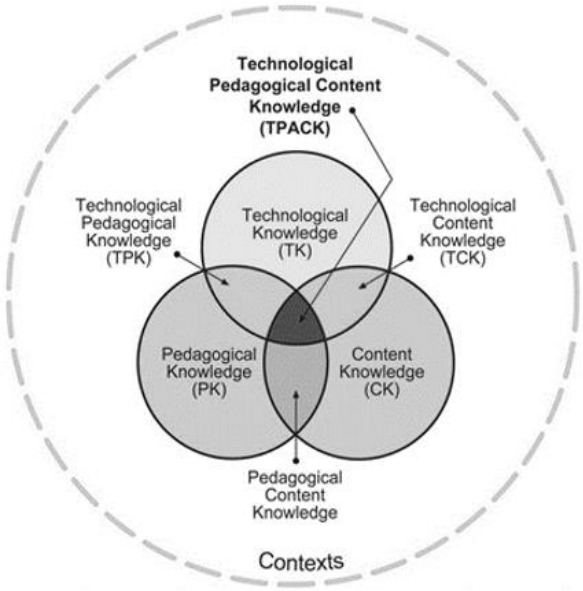

Figure 1. TPACK framework

the key idea of each aspect of the TPACK framework to teach effectively using educational technology in the classroom. Teachers need to find a productive way to convey and combine those three larger areas of content, pedagogy, and technology in their lessons (**Figure 1**).

The TPACK Component

Many scholars have characterized the seven components of TPACK. Here, the researcher synthesized each component from Koehler et al. (2017), Lin et al. (2013), and Mishra and Koehler (2006). However, models of teacher knowledge are always challenging because the work of a teacher is complex, and it is not easy to describe a list of domains of teacher knowledge (Guerriero, 2014).

Shulman's (1987) model divides teacher knowledge into CK, PCK, and general pedagogical knowledge (GPK) (Carlsen, 1999; Hashweh, 2005), which is in line with several other authors like Arnold et al. (2012) and Verloop et al. (2001). Also, a teacher needs contextual and curriculum knowledge (Gess-Newsome, 1999). CK is about the actual subject matter to be learned or taught, that is, facts, concepts, theories, ideas, and organizational frameworks and skills like observing, classifying, and interpreting, and using evidence for making an argument. CK is the knowledge teachers use in designing their lessons (Koehler et al., 2017; Lin et al., 2013).

GPK is the knowledge of pedagogy that is potentially generalizable across subjects and even disciplines. Auerbach and Andrews (2018) stated that GPK may include knowledge of theories of learning, general principles and approaches to instruction and assessment, lesson structure, classroom organization and management, student motivation, and other types of knowledge (e.g., König et al. 2014; Morine-Dershimer & Kent, 1999; Shulman, 1987). GPK is knowledge about instructional processes, techniques, or methods to be used in the classroom, which encompasses educational purposes, values, aims, and all issues related to student learning, classroom management, lesson plan development, and implementation.

PCK is the synthesis of the knowledge needed to teach a certain topic (Carlsen, 1999). According to Gess-Newsome (1999), the following areas of teacher knowledge have been associated with PCK:

1. teaching or instructional strategies, assessment strategies, and collaboration strategies (shortly teaching methods);
2. knowledge about student interest, motivation, and the learning of conceptual and procedural knowledge and skills;
3. knowledge of learners, such as student thinking, misconceptions, and cognitive and affective demands of tasks and activities;
4. knowledge about the resources available to support teaching and scaffold learning; and
5. curriculum knowledge and goals of student learning (Abell et al., 2009).

In the European tradition, especially in Germany, France, and the Nordic countries, including Finland, the term 'didactics', or more precisely, 'didactical transformation' (in German, didaktische transformation) (Kansanen, 2002) refers to processes that are similar to those included in PCK.

Technological knowledge (TK) is knowledge about the use of technology (e.g., operating systems and computer hardware, mobile phone, sets of software, and programs (e.g., word processors, spreadsheets, browsers, educational applications, Zoom, Microsoft Teams, social media, and e-mail) in teaching and learning specific subject areas in the classroom (Fuad et al., 2020). Technological content knowledge (TCK) is knowledge about applying technology to represent CK, but this does not relate to its pedagogical purpose. One example of TCK is knowledge of using computer graphics to present the existence of mammoths in the ice age. Technological pedagogical knowledge (TPK) is knowledge about applying various technologies in pedagogy for teaching and learning all subject domains rather than being focused on specific CK, such as using Zoom to organize students' lesson learning. To conclude, a teacher employs TPK or digi-pedagogy when he or she uses technology or guides students to utilize educational technology in learning. This TPK includes TCK or the skills needed for using educational technology or digital tools, platforms, and digital environments for teaching and learning, as well as the knowledge and skills needed to support students' engagement, learning, and well-being in digital environments (Greenhow et al., 2021).

TPACK refers to knowledge about the use of technology in teaching or in learning. Teachers have

Table 1. Indicators of TPACK (modified from Kurt, 2018)

Key ideas of TPACK	Abbreviation	Indicator of each key idea
Using technology to teach content knowledge	K1	-Ability to integrate teaching methods with the use of appropriate technologies (K1.1). -Use educational technologies (e.g. Facebook, Kahoot, Plicker, Prezi, and Canvas) that facilitate subject-specific science activities in the class (K1.2). -Use educational technologies to help students observe, explore, and learn the subject matter to support scientific inquiry in the class (K1.3).
Using technology to ensure versatile communication; to guide students to utilize educational technology in learning; to support students' engagement, learning, & well-being	K2	-Ability to design collaborative and interactive activities which are mediated interaction by the use of appropriate technologies (K2.1). -Ability to use learning management systems, such as, Google Forms, Moodle, or Courseville, to teach content knowledge (K2.2). -The use of social media (e.g. Facebook, Line, chat programs, blogs, wikis) to support communication (K2.3).
Educational technology can enhance students' existing and prior knowledge or develop new knowledge	K3	-Use educational technology to address learner misconceptions related to a subject area (K3.1). -Develop alternative assessment strategies with technology by focusing on authenticity rather than techno-centricity (K3.2).
Different backgrounds of students in the classroom, including prior educational experience and exposure to technology; teachers should recognize this issue	K4	-Before designing the teaching and learning activities, teachers survey the states, problems, and limitations of students in the area of readiness of using technology and technological equipment (K4.1).
Different content concepts & student skill levels; educational technology can help in these areas	K5	-Design the activities using educational technologies to teach students which are suitable for their age and skill (K5.1).

good TPACK when their content, pedagogy, and technology are well integrated to facilitate students' knowledge construction in a specific context. This view of TPACK seems to be teacher centered, but students' interaction (student-student, teacher-student) and students' collaboration are considered to be indicators of TPACK, as shown in **Table 1**. The key ideas of TPACK in this research are presented below.

Education During COVID-19 in Finland

In Finland, schools switched to remote learning from March 18, 2020 to May 13, 2020 (Ahtiainen, 2021). The schools were able to organize remote learning because of teachers' and students' ICT skills and the availability of ICT devices. According to Organization for Economic Co-operation and Development (OECD, 2020), 74% of teachers reported that ICT skills for teaching were included in their professional development activities, and 94% of students have computers they could use for schoolwork. Finnish schools used Wilma as the core platform in primary schools to provide homework, give feedback, and communicate with parents (Visma, 2020) along with other general platforms, such as Moodle, Google Classroom, Skype, and Zoom, depending on the education provider (YLE, 2020).

Finland was found to be successful in remote learning during COVID-19 in numerous Finnish reports and studies due to the high professional skills of teachers and society's investment in digital education infrastructure. In addition, the Trade Union of Education in Finland reported that 61% of teachers delivered real-time teaching apart from only using the core platform to assign work, and students who received more real-time teaching were likely to be assessed positively during the remote learning period (Finnish National Agency for Education, 2020). Lavonen and Salmela-Aro (2021) summarized the experiences of Finnish teachers and students during the COVID-19 pandemic using surveys and case studies. They found that the preconditions for organizing effective distance teaching and learning in Finland were in place: teacher and student digital competencies were at a good level, the digital infrastructure was well established, and digital tools were available. The most serious threats to students' well-being have been the limited options for collaboration and interaction as well as social isolation and loneliness during the pandemic.

Education During COVID-19 in Thailand

In 2020, the Office of the Basic Education Commission (OBEC) used an evaluation form to evaluate primary schools' readiness for contact learning during the COVID-19 pandemic. The results of the evaluation divided schools into three groups:

1. **Green group:** ready and able to arrange contact learning;
2. **Yellow group:** managed a safer environment for contact learning and was able to reopen when school safety standards were met;

Table 2. Total number of participants

Grade level	Number of participants (Finland)	Number of participants (Thailand)
3	1	2
4	2	2
5	2	2
Total: 11	5	6

3. **Red group:** not allowed to arrange contact learning, and had to provide remote learning instead (OBEC, 2020).

The red group had to provide online learning for students through general online platforms, such as the Line Application, Zoom, and Google Classroom. Researchers from Kasetsart University studied teachers' and students' readiness to implement online learning and found that 55.7% of teachers believed that online learning was less effective than on-site learning, and only 45% of students were able to participate in online learning due to the lack of devices and internet connections (Fakcharoenphol et al., 2020). Promwong et al. (2021) reported that teachers preferred on-site learning during COVID-19 and thought that online learning was the hardest method to implement. Moreover, the researchers suggested that students should be given digi-devices in order to follow the OBEC regulations for on-site learning, for example, setting up classrooms with social distancing, always wearing masks, and dividing students into smaller groups to perform activities separately.

Due to the COVID-19 situation, the Minister of Education has been asking primary schools for cooperation to reduce students' work, assessments, timetable density, and to provide device support to help students have less stress and learn more effectively (Thaipost, 2021).

For this paper, we selected Finland and Thailand as cases based on several reasons. There are several reasons for comparing Finland and Thailand. First, the education systems are different, and this allows variance in teachers' experiences. Two different education contexts increase the variation in the teachers' interviews, which is important for understanding the big picture of COVID-19 related education. Second, even the countries and their education policies are different, in both countries, the schools have been closed for around 30-40 weeks during the pandemic. The education providers, in both countries, have aimed to support teachers in their distance teaching and learning (UNESCO, 2021). We thought that in a Eurasia journal this type of comparison is interesting. Third, in both countries, the curriculum emphasizes rather a similar way the employ of TPACK in the planning of lessons. In Finland, the national framework curriculum for compulsory education emphasizes as a part of the description of transversal competences that students should be able to do the following: learn to use digital tools in diverse and creative ways; collaborate and network with digital tools; and work with data, information and knowledge (FNBE, 2014; Ministry of Education and Culture [MEC], 2017). In a similar way, in Thailand, the aim is to transform teaching and learning so that the development of student competencies, including digi-competencies, and the use of knowledge and skills are the primary focus of education (Delaney, 2019). All government sectors in Thailand advocate that use of digital tools in education should be guided by professional teachers. The Teacher Council of Thailand (2005) developed minimum specifications of ICT competency and computer skills for teachers. The OBEC (2010) has further specified research to enhance ICT competency. This allows us to interpret data in-depth and took into account also the educational contexts in these interpretations.

RESEARCH METHODS

The current study followed a case study approach to answer the research questions. According to Merriam (2009), the important aspect of case studies is determining what the case is, which also corresponds to the unit of analysis. In our case study each interviewed teacher, who has employed TPACK for finding BL solutions to his/her classroom during COVID-19 was considered as case. Yin (2003) has underlined that case studies are appropriate research methodology for studies focusing on "how" questions related to phenomena within a real-life context. In order to answer our "how" question, semi-structured interviews were conducted. The interview protocol (in the attachment) emphasized the concepts of TPACK in science teaching and learning during COVID-19 in Finland and Thailand.

Participants

There were 12 voluntary primary school teachers, six Finnish teachers in Helsinki, and six Thai teachers in Bangkok, who were interviewed for this study. The teachers were working in 'ordinary' comprehensive schools and demonstration (teacher training) schools (**Table 2**).

In the context of TPACK, it is important to consider the topics taught in science class, and therefore the grades and topics were carefully selected for the purposes of this study. According to Creswell (2013), this type of purposive sampling is suitable for qualitative studies where the researchers are interested in informants who have the best knowledge concerning the research topic.

The general criteria for the selection of teachers were, as follows:

1. Teachers had taught science in grades 3-5.
2. Teachers had at least five years of teaching experience in science.
3. Teachers conducted science classes both online and on-site during COVID-19.

12 teacher participants were recruited based on these criteria, but one was unable to answer because of a COVID-19 infection. Therefore, 11 teacher participants provided the interview data.

Interviews

Semi-structured interviews were the main research method (**Appendix A**). The interviews were conducted and recorded via Zoom for all participants. There were several open-ended questions, which allowed the teachers to describe how they employed TPACK in BL situations through science instruction. In Thailand, the researcher sent letters to the principals requesting their permission to interview the teachers. Then, the interview appointment was agreed to. In Finland, the teacher connection was made directly by the co-researcher, and the interview appointments was set. The teachers were informed by email of the date and time for the interviews and asked to participate, and five agreed to participate voluntarily. The teachers had the ability to cancel their participation at any time during the interview.

Thai and English were the languages used for interviewing. The interviews lasted from half an hour to two hours per participant. The researcher asked permission to record voice and video and to begin with general questions about the participants' lives. Then, the researcher asked all the questions in the interview protocol (see the references). In the beginning, the interviewer introduced herself to the teacher. Most teachers were somewhat nervous about the questions, but after 30 minutes the participants' gestures and manners suggested that it was a situation in which both parties could receive in-depth information from the interview. Importantly, leading or suggestive questions were avoided. The teachers were allowed to express their viewpoints freely based on the question aims and the available time.

The interviews were analyzed using deductive content analysis (Elo & Kyngäs, 2008). The transliterated texts were read many times to ensure an accurate interpretation of the teachers' expressions. Keywords were extracted from the transliterated texts. The written texts were read again and written down and grouped into the margins as necessary to describe all aspects of TPACK. Consequently, the results of the synthesized interviews were presented in the form of a narration and a table. Examples of direct quotations from the teachers supporting those ideas are presented.

In our deductive content analysis, we first developed **Table 1**, which introduced indicators of TPACK. These indicators were used as the main categories. According to Schreier (2012), the categories could be regarded as valid if the categories adequately represent the phenomena and capture what was intended. In our case, the categories come from the TPACK model, and our aim was to study how the interviewed teachers employ TPACK while describing their COVID-19 teaching. In the reporting phase, we followed again the suggestions of Elo and Kyngäs (2008) and described the phenomena with the categories to guarantee the validity of the study. The coding of the interview data was done first by the first author of the paper. The first author is working as an assistant professor in teacher education in a research university. For increasing the reliability, the second author went through the coding and took all the unclear codes to further elaboration and for making a common decision on the codes. There were 12 this kind of unclear codes. The second author work as a professor in teacher education in a research university. Both authors have published several research papers using deductive content analysis.

Lincoln and Guba (1985) use the term trustworthiness instead of validity and reliability for supporting the argument that the findings of the qualitative study are "worth paying attention to". They proposed four alternatives for assessing the trustworthiness of qualitative research, that is, credibility, dependability, conformability, and transferability and, moreover, add later also authenticity. From the point of view of credibility, we have introduced researchers who have participated in the research. Selection of an appropriate method, in this study deductive content analysis, is essential for ensuring the credibility of content analysis. Dependability refers to the stability of data over time. This was the reason why the second researcher ensured that he was able to follow the decision the first researcher made in the coding. Conformability refers to objectivity. Before the coding, the first author read the interviews several times and then coded them according to the categories. After coding, the second author read the interviews and coded data to convince himself that the data accurately represent the information that the interviewed teachers provided. Transferability refers to the idea that the study could be replicated with the same or similar participants in the same context. The saturation of the data in both countries indicates transferability. It happens in both countries that the last or last two teachers did not actually add anything important the previous teachers already emphasized. For increasing the authenticity of the study, we introduced the education context in Finland and in Thailand and, moreover, provided information about the COVID-19 time teaching and learning in general with references. (Elo & Kyngäs, 2008; Lincoln & Guba, 1985).

Table 3. Personal information of the participating teachers

Items	Finland	Thailand	Mean	N=11
Gender				
Male	1	1		2
Female	4	5		9
Total				11
Age	45	37	41	11
Years of teaching experience	17	11.5	14	11
Type of school for teaching				
Public school	3	3		6
Demonstration school	2	3		5
Total				11
Degree of highest education				
Doctoral degree	1	0		1
Master's degree	4	6		10
Total				11
Teaching awards	0	2		11
Other positions	1	6		11

RESULTS

The results are presented in two parts:

1. personal information and
2. analysis of the teachers' interview transcriptions from the point of view of employing TPACK in teaching and learning science during COVID-19.

Personal information data are shown in **Table 3**.

Almost all of the participants had a master's degree, and one Finnish participant had a doctoral degree. There was one Thai teacher who received an award as the best science teacher from the Chanthaburi Primary Education Area 1 Office. Another Thai teacher was recognized as an outstanding educator using technology for teaching and learning by Apple in the Asia-Pacific Region. Almost all of the Finnish teachers had another position besides teaching roles, including a supervising student–teacher role.

In addition, three Thai teachers had a supervisory role, and one Finnish teacher was an ASPnet National Coordinator (UNESCO). Moreover, all Thai teachers had other positions, such as the head of school projects, head of science subject teaching, student–teacher supervision, and vice deputy director school in foreign affairs and special affairs. Consequently, the interviewed teachers were experienced forerunner teachers in both countries. Therefore, the interviews provided more than just a basic picture of activities at school or what had been possible to do in schools during COVID-19 but the teachers' interviews were reflected the aspect of TPACK too. However, from the perspective of the research and the development of practice, the selected teachers provided an appropriate perspective.

The teachers' expressions of their ideas and experiences of TPACK in science teaching are presented in **Table 4**.

DISCUSSION AND CONCLUSIONS

The main result of this research project was that the Finnish and Thai primary school teachers' science teaching experiences during the COVID-19 pandemic both on-site and online reflected all recognized areas of TPACK (Kurt, 2018; **Table 1**). All of the interviewed teachers employed technology, pedagogy, and content knowledge and combined them in their online teaching. For on-site teaching, they only used technology sometimes in some teaching steps. Therefore, TK, TCK, TPK, and TPACK (Fuad et al., 2020; Kurt, 2018) are vital areas of primary teacher knowledge that they must be able to employ in various science teaching and learning situations.

The TPACK framework help teachers to teach effectively using educational technology in the classroom (Kurt, 2018). In the interviews, all of the teachers emphasized the importance of hands-on activity through the experimentation method both on-site and online. However, the realization varied between the teachers: in the on-site teaching, students performed experiments with the lab equipment in a small group according to the teacher's step-by-step illustration without using technology. As Sothayapetch et al. (2013, p. 94) proposed,

> "laboratory method and experiments performed as group work. Students had to discover and solve the problems together in pairs, in small groups, or by themselves under the teacher's facilitation."

Therefore, the students obviously observed things and inquired about the phenomena in front of their faces. In online teaching, it is difficult to have the students work in a small group, so the teachers used the technology to cope with this problem and attempted to help the students achieve the learning goals.

Table 4. The synthesized results of the teachers' interview data

The aspect of TPACK	BL	
	On-site	Online
	Using technology to teach content knowledge (K1)	
K1.1	Laboratory method with lab equipment was used. Students learned the content through hands-on activities and discussion in small groups. The contents were shown in several ways, such as textbooks, pictures, PowerPoint presentations, and YouTube videos with the teacher elaboration. Discussion was used too. Students learned to ask questions and find the answers on their own.	Demonstration methods based on remote synchronous teaching demonstration and asynchronous video-based lessons were employed. Together with pictures, teachers' video clips and YouTube videos were used to guide the student's hands-on activities. Teacher-LED instruction is a Finnish instructional model. Finnish teachers led the students to share experiences through discussion based on the content of the lesson.
Quotations of participants	"When I taught at school, I used LAB methods all the time to teach the students. Before having class, I had to prepare the equipment for the experiment in the LAB every time" (TP3, Oct 12, 2021). "So when we are in a classroom so science dictating which we try to make it as much based on students' own questions and own experiments as possible" (FP2, Nov 15, 2021).	"I began with showing picture to arouse student observing, then I demonstrated through video conferencing (Zoom). Students followed together with teacher describing by hands-on at home. In teaching a light experiment, students used a lit candle, a torch, etc. standing for sun" (TP5, Oct 14, 2021). "I mostly used teacher-led instruction in online teaching because it was so difficult for those with problems with self-regulation, & they needed a very clear structure" (FP5, Dec 20, 2021).
K1.2	-All participants guided their students in experimental or inquiry activities in a small group. Students discussed the scientific content and experimental stages in the group. The participants used the pre-recorded video clip, textbook, and exercise book to convey the students' content and activities procedure.	**-Arousing the students' interest** The participants introduced the lesson by showing pictures or turning on the pre-recorded video clips/YouTube videos to arouse the students' interest and let them share the idea with classmates. **-Presenting the scientific content** All of the teachers asked students to read the textbook and work on an exercise book or online worksheet. Moreover, the students watched teachers' pre-recorded video clips or YouTube videos, and the teacher gave a lecture by sharing a PPT presentation with video conferencing. **-Learning process/hands-on activity** Zoom or MS Teams were used as the main learning platform. For the learning activities, the teachers used many game-based platforms to organize the learning process, including Roblox, Kahoot, Quizizz, Wordwall, and Liveworksheets. The scientific concepts were reflected in photographs or short recorded videos made by students with mobile phones. Other assignments like posters or infographics created with Canvas, PowerPoint, or MS Word demonstrated their learning, and they then submitted these works via Google Classroom.
Quotations of participants	"I totally provided the students making a real experiment. I sometimes used YouTube videos to amplify their content in the lesson. I still used a textbook and notebook for the students' learning" (TP6, Oct 18, 2021). "I like to use very much hands-on, which means I like to teach students to practice themselves and test something" (FP3, Nov 17, 2021).	"I focused on video clips quite much. A better point is all students could see the presentation clearly on the screen. However, textbook and notebook were still important for the students" (TP5, Oct 14, 2021). "I have used textbooks, online materials related to the textbooks, and other relevant texts and pictures, both online and face-to-face teaching. I also have used experimental devices and simulations and videos" (FP5, Dec 20, 2021).

Table 4 (Continued). The synthesized results of the teachers' interview data

The aspect of TPACK	BL	
	On-site	Online
K1.3	The teachers usually used open-ended questions to guide students' thinking about the topic, from a certain point of view. Next, the students learned through experiments or hands-on activities and conducted experiments by following the guidelines in the textbook and/or the teacher's instructions. The scientific inquiry appeared from students' planning, observations, and discussions within the group. There was little use of technology in these situations.	-A box of experimental equipment was provided to the students to learn at home. This helped the students to make their own experiments and not just follow the teacher's demonstration step by step. Most often, students could observe independently while a teacher conducted an experiment/presented a video clip. Other activities to support the learning of scientific skills were as follows: 1. The students recorded a short video clip related to the content lesson. They observed the phenomena according to the video clip they made. Then, they could observe, inquire, and discuss with the teacher and their friends. 2. The teachers presented the pre-recorded video lesson or online simulation lesson together with questions to motivate the students' thinking about things that happened in the video via Zoom or Microsoft Teams.
Quotations of participants	"I followed the 5E model of teaching. Engagement is the first E, so I showed a picture or video clip related to the lesson, then asked an open-ended question to help the students think and share some ideas. The next E is Explore. I put the students into small groups to perform an experiment or sometimes a hands-on activity. They explored the situation that happened in the group to find the answers" (TP2, Oct 9, 2021).	"I wanted my pupils to be able to study equally at home. So, I made a package for pupils that included planting tools, laboratory equipment, and materials for growing a pea plant at home. I guided pupils' inquiry-oriented learning via video lessons" (FP1, Nov 13, 2021). "I have also used experimental devices and simulations and videos" (FP5, Dec 20, 2021).
Using technology to ensure versatile communication; to guide students to utilize educational technology in learning; to support students' engagement, learning, and well-being (K2)		
K2.1	The collaboration of students occurred when they were in small groups, so the interaction was presented in many ways, such as talking, answering, and discussing with teacher and friends. It was not necessary to rely on the technology.	-The teachers supported the collaboration and interaction with technology, as follows: 1. The teachers opened breakout rooms in the Zoom meeting. They brainstormed together and produced the group work via the Zoom whiteboard or annotations to add, remove, or revise a written work of friends in the group. Likewise, the Microsoft Teams whiteboard allowed the students draw, sketch, and write together on a shared digital canvas. Moreover, the students could respond and react by chatting and clicking the reactions in the Zoom chat. 2. Kahoot, Quizizz, and Wordwall were used to stimulate the interaction of students in the lesson or they interacted with the quizzes and other uploaded files. Moreover, Vonder Go, a Thai game-based platform, was mostly used by Thai participants to activate the students' collaboration in competing against the enemy in the game.

Table 4 (Continued). The synthesized results of the teachers' interview data

The aspect of TPACK	BL	
	On-site	Online
Quotations of participants	"In normal class, of course, the interaction between teacher–student and student–student happened very easily because based on the nature of learning science, students had to work together in the group for experimenting" (TP2, Oct 9, 2021). "I can say that I never sit at the teacher's desk in class. Instead, I walk around the class, stop by the students, ask questions, and encourage them to try harder. I give feedback about their studying, tasks, or group learning" (FP1, Nov 13, 2021).	"Yeah…yeah for pupils I created a break room like things where they go with…I can go around the break rooms, but it was still very confusing because I can follow one break room at the same time" (FP3, Nov 17, 2021). "I liked to check the students that they were still with me by asking the questions, then letting them type the answer in the box chat on Zoom" (TP1, Oct 7, 2021). "I created the questions of the lesson or sometimes uploaded worksheets via google form. This kind of feedback from the students showed whether they understood the content lesson or not" (TP3, Oct 12, 2021).
K2.2	On-site instruction, teaching, and the learning process mainly happened in the classroom. All teachers designed instructions by creating lesson plans, based on the national curriculum.	-The participant teachers utilized several learning management systems in the online class, which are described below: **<u>Platform for instruction</u>** 1. School platforms like Wilma and CUD on Smart School were used to arrange the students' learning. All Finnish teachers employed Wilma, and two Thai teachers used CUD on Smart School. 2. Zoom and MS teams were frequently used to organize the teacher instruction during COVID-19 in both countries. 3. Google Forms was the tool most participants used to create documents like worksheets, assignments, schoolwork, lesson exercise, etc. for the students. 4. Google Drive is an alternative way for teachers to collect all documents relating to their own teaching documents and students' learning document.
Quotations of participants	The instruction happened at school.	"We have CUD on Smart School. It is an education platform for teachers, students, and parents to use during the COVID-19 time" (TP6, Oct 18, 2021). "I've used Microsoft Teams with online teaching" (FP4. Dec 7, 2021). "I have used MS Teams for teaching and communication with students and the Wilma platform for communicating with parents" (FP5, Dec 20, 2021).
K2.3	-All Thai participants created a Line group to support communication among teachers, students, and guardians, but the Finnish teachers did not use social media for the on-site instruction.	During the online instruction, some Thai teachers set the Line group to communicate details about the instruction to parents and guardians. A few Thai teachers created a private group on Facebook as a channel to exchange ideas and comments from parents/guardians about the taught lesson. Finnish teachers communicated through the Wilma platform.
Quotations of participants	"Before COVID-19, I opened the Line group as the way for communicating with students and their parents…in case they will have any problems with the lesson instruction" (TP4, Oct 14, 2021). "I called them to let them know I need five minutes to discuss with the parents, so we will have a meeting in Teams, then we discussed so this kind of two ways I used. I have my personal phone" (FP2, Nov 15, 2021).	"Of course, I have to use the Facebook group for communication with students, especially for students' parents because elementary students always have many problems, such as homework, exercises, so I can follow them about the work from their parents" (TP1, Oct 7, 2021). "I used Wilma as the channel to communicate more about my teaching and students' learning" (FP3, Nov 17, 2021).

Table 4 (Continued). The synthesized results of the teachers' interview data

The aspect of TPACK	BL	
	On-site	Online
Educational technology can enhance students' existing and prior knowledge or develop new knowledge (K3)		
K3.1	Both Thai and Finnish students were allowed to Google the content in the lesson individually and collectively using a mobile phone or tablet in the classroom. All of the participants checked the students' conceptual understanding of the lessons by asking questions, letting them explain the concept if they misunderstood the concept the teachers explained by presenting the video clip or pictures.	Likewise, in the on-site teaching all of the participants used the internet as a source to find more information about the content of the lesson. The teachers designed the learning activities as group work (breakout rooms in Zoom/MS Teams). The students had to brainstorm with others in the group to find the information related to the concept lesson or answer the exercise from the online worksheets.
Quotations of participants	"Normally, I tried students to find the keywords first that related to the concept in the lesson. Then, the students wrote the short concept on their own. If they were not sure about their writing, they could use the iPad or tablet to find out more detail on the Internet" (TP1, Oct 7, 2021). "I write key concepts for display on the board. After this exercise, students read aloud or in a small group a textbook or from the internet on a topic from my designated sites on the subject" (FP1, Nov 13, 2021).	"For online, I put them into the breakout room to share ideas and help together to find out more detail about the concept of that lesson. They searched information on the internet, that's very easy for their gen" (TP5, Oct 14, 2021). "For example, I've taught to build a simple scale with a coat hanger and some plastic bags during the online lesson. After that, my students got their own exercise with home-build scales and they reported their findings on our shared platform on Teams" (FP4. Dec 7, 2021).
K3.2	Thai teachers mostly used the test to assess students' knowledge, but the Finnish teachers did not use the test. However, all of the participants used formative assessments or observed and guided students during the learning process, providing feedback on learning-in-process and steering the process toward the aims. Moreover, the teachers assessed the student's behavior and collaboration in group work by rubric scoring.	It was difficult to use the test for students in this online situation. Most of the participants selected the formative type of assessment or observations in order to check the workgroup process and participation in the class. Moreover, parents or guardians gave the teacher feedback about the teaching and learning in the class. There were also assessments of project work, individual work (home test), and the developed model.
Quotations of participants	"The paper test is still important to check the students' learning achievement, but in addition to the test I also usually assessed students' skills through formative assessment. I assessed the scientific skill from the group project by rubric scoring" (TP3, Oct 12, 2021).	"At the end of the semester, I got feedback from the guardians who said that they were impressed with how technology was able to support their kids' learning as well as interest in schoolwork" (FP1, Nov 13, 2021). "I had quite normal tests, only converted in MS Teams tasks. I also evaluated the tasks the students sent me every day" (FP5, Dec 20, 2021).
Different backgrounds of students in the classroom, including prior educational experience and exposure to technology; teachers should recognize this issue (K4)		
K4.1	Never survey	There were no problems with the use of technology in Finland. There were some problems in Thailand after the teachers surveyed the states and problems. For example, some students had no devices to learn online, or the internet signal was weak. The school supported the students by assigning them devices.
Quotations of participants		"Most students learned in a couple of days to use technology. If they had problems, they had the possibility to call me, and then I assisted them personally. They also helped each other" (FP5, Dec 20, 2021). "I surveyed the students' problems in each home. I found that a few students didn't have mobile phones to learn, so the school allocated them for those students" (TP5, Oct 14, 2021).

Table 4 (Continued). The synthesized results of the teachers' interview data

The aspect of TPACK	BL	
	On-site	Online
Different content concepts and student skill levels; educational technology can help in some of these areas (K5)		
K5.1	Little use of educational technologies in designing the lessons or activities.	-Selecting a platform that is easy to use and not overly complex for the students. -Providing the option to use various devices to learn online, such as desktop PCs, mobile phones, tablets, or notebooks. -Designing the assignment in the best way for the students, such as photographing, typing, or recording videos. -Selecting an educational game to support the student's learning that was suitable for their age and level of study, such as Booklet, Kahoot, Quizizz, and Vonder Go. -Using animations, cartoons clips, and authentic objects to present the lesson content. This could support and arouse the student's intention to learn in a fun way.
Quotations of participants		"I think elementary students like to compete with other friends. So I select the Vonder Go and Kahoot to stimulate them to stay with me for the whole time class" (TP2, Oct 9, 2021). "Animation clip was the one learning material for online teaching that introduced the students' attention easily if I used the documentary clip it could not draw the students' attention, vice versa they felt bored and were far from their lives" (FP3, Nov 17, 2021).

The teaching method was changed from lab experiments to demonstration. The teachers used pre-recorded videos and YouTube videos to teach the students. When teaching online, it is very difficult to have work on a lab together, so the video presentations represent an optimal alternative in this case. The teacher's illustration of conducting an experiment introduces the students to the step-by-step process of the experiment, and the students can observe each process in the pre-recorded video through videoconferencing (Zoom and MS Teams). As Alber (2019) noted, teachers are always seeking new ways to extend their curricula, and video clips are a great tool for helping students gain an in-depth understanding of the content. The use of video supports students' thinking, learning, and discussion of science ideas (Higgins et al., 2018).

When students learn online they lose the ability to work with friends in small groups. They cannot engage in group discussions and make common observations. Sutton (2020) suggested that teachers should provide students with an opportunity to share prior experiences and clarify their thinking with the help of their classmates. Accordingly, besides video recording, other tools, such as screen-castify and screen-cast-O-Matic, can be utilized by science teachers to promote peer interaction and vocalization of their ideas through screen-casting, stimulating structured and purposeful communication. Responsive feedback is an important component of student discourse. Students can immediately view a peer's explanation of a natural phenomenon and reply to that student's work on a shared Google Doc. Guiding questions can be used, such as 'what would you like to know more about?'

The analysis of teachers' interviews indicated that the interaction between teacher-students, students-students, and students-technology played an important role in BL, especially in online instruction. The teachers were able to support students' interactions through the use of appropriate educational technology. However, because of the nature of online learning, the teachers could not approach each student at the desk as they did normally in their class in on-site teaching. Various video-conference platforms, such as Zoom, MS Teams, and Google Classroom, and their tools, such as chat, break out room, uploaded files, web pages, links and directories, mediated interaction. These were used in the interaction between teacher-students, students-students, students-technology, and teacher-technology. Also, most teachers used educational games via online platforms to support students' learning and thinking during the lesson, enhance the student's learning by themselves, improve students' skills, or help to wrap up the whole lesson. Teachers asked questions during online sessions but also through uploaded files, and online quizzes like Kahoot, Quizizz, Voder Go, and Wordwall. This meant that the teachers created the quiz questions and the interaction happened between the teacher and students through the use of education technology. Likewise, the students interacted with the online content by reading the uploaded files, the teachers downloaded to the platform after the class, or playing the online game on their own and with friends in the class. Felszeghy et al. (2019) investigated students using

online game-based platforms to improve students' performance and engagement in histology teaching. The results found that Kahoot increased their motivation to learn and made collaborative team- and gamification-based learning positively. These were examples of technology-mediated interaction, which, for example, Ping (2011) has recommended to be included in online learning for allowing the quality interaction between the learners and content, learners and teacher, as well as learners and peers. The interaction with content should not just be a one-way interaction via a pure text display or conversion of learning materials to digital forms. Encouragement, support, and feedback play a vital role in eliminating the negative feelings associated with online learning. Feedback can be broadly defined as the interaction between learner-instructor, learner-learner, and learner-learning management system.

Elementary-level students need reinforcement from the teacher when they study. Based on the interviews, the participants managed and organized the class activities using a game-based learning platform to increase the students' motivation to participate in online instruction. Because elementary-level students have limited concentration, they need challenging activities to maintain their attention in class. The participating teachers used activities to grab the students', such as game-based learning platforms (e.g. Kahoot, Quizizz, Voder Go, and Wordwall) in online classes. Moreover, the participants' demonstrated flexibility in online teaching, such as a 15-minute between classes and reduced content lessons, reflecting the teachers' understanding of child development. As some participant teachers expressed,

> "For the on-site class, I had 60 minutes to teach the students but for the online class I had to reduce the time to 45 minutes. I left them 15 minutes before the class ended to help them relax for the next class" (TP3, TP6, FP3, and FP4).

According to Ward (2020), many experts believe that the attention span of children is only two to three minutes per year of age, and to improve their attention span they should be given short breaks and offered fun activities. The appropriate attention span for grade 3-5 students should be 18-36 minutes per class time. Furthermore, many previous studies showed that game-based learning platforms such as Kahoot and Quizizz can increase students' motivation, improving the learning experience and increasing student engagement (Licorish et al., 2018; Martín-Sómer et al., 2021).

Another important point is the use of textbooks in both online and on-site teaching by the Thai and Finnish teachers. The texts from the interviews show that all teachers valued textbooks even though they instructed students online. Indeed, the textbook is a tool to convey the content subject between teachers and the national curriculum. Many Finnish and Thai teachers expressed that textbooks are vital for learning science, and they are a primary resource for finding information related to the content lesson. Students are able to follow the content and guidelines in the textbook as the teacher is explaining a scientific concept or demonstrating an experiment through videoconferencing. Smart et al. (2020, p. 8) suggested that

> "science textbooks, even in contexts that lack laboratory equipment, can acknowledge the nuances of science as well as its social implications."

However, one challenge that arises when students learn from a textbook individually and in a small group (breakout room/teams) is how to activate students during their reading. For example, reciprocal reading aims at activating students to read and study in groups. Students are instructed to form pairs or small groups after independently reading for a short while (one page), and then the following activities can be carried out (Miller & Veatch, 2010). Textbooks have important role in BL. They were important sources of information and offered various types of assignments, supportive for students learning. However, the interaction and actions around the textbooks were mediated through technology. Consequently, the textbooks have a similar role to any other sources of information in the TPACK-framework, such as web pages, games, or YouTube videos, although they were in printed form. Some Finnish and Thai teachers used e-textbooks during the COVID-19 time (FP1, FP3, TP2, and TP4). Roberts et al. (2021) proposed that e-textbooks have several advantages such as the area of cost compared to print textbooks, student engagement, reading comprehension, and mobile learning. E-textbooks offer features that can lead to increased interaction between students and the learning content and between students and teachers.

In conclusion, all of the participating teachers in both countries employed TPACK in their online science teaching during COVID-19, familiarizing themselves with typical student pre-conceptions. They followed the educational technology in designing their instruction in terms of providing the lesson content, learning activities, and the students' learning assessment. The Thai participants instructed the students through Zoom, while the Finnish participants utilized MS Teams as the videoconferencing platform. All of the participants brought the technology into their science teaching in school. For example, they represented the lesson content or illustrated the experiment using PowerPoint, YouTube videos, and pre-recorded videos. In online instruction, they took the educational technology into account in every step of their teaching to enhance the students' learning of science as much as possible. All of the participants attempted to shape the students' learning (e.g. the concept of the science lesson, scientific skills, communication, and interaction) in on-site

studies. For this paper, the researchers focus on primary teachers and how they employed TPACK while designing their lessons during the COVID-19. Therefore, we focused on teachers' criteria–not to the criteria for the schools. Teachers as cases was emphasized in this case study. The COVID-19 pandemic has been one example of unexpected events education systems can meet, but it provides an opportunity to understand how schools could respond during an unexpected. The current challenge in many European and Asian countries is organization of education of young refugees. The lessons learned through COVID-19 time studies could be utilized in any studies, which focus on unexpected events in education systems.

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APPENDIX A

Interview Protocol

Structured Interview Form for Elementary School Science Teachers at Grade 3-5

Research Title: Technological Pedagogical Content Knowledge of Primary School Science Teachers During the COVID-19 in Thailand and Finland

Objectives of Research

1. To investigate the TPACK of Finnish and Thai primary school teachers in the context of teaching science.

Explanation

1. This structured interview form is used for Finnish and Thai science teachers at grade 3-5 level. The interview is asked about science teaching and learning under the form of blended learning during COVID-19 situation.
2. The period of interviewing does not exceed two hours.
3. If the interviewees are unavailable to answer, they can skip or do not respond.

Name of interviewee: ……
School name: ……..
Taught grade: …….
Interview date: ……...
Start time: ……...
Finish time: …….
Place interview: …….

Part 1: Personal Information

1. How long have you been teaching in this school?
2. What is your highest degree achieved? What was your major?
3. In what grade do you teach now?
4. Do you have another position besides your teaching role?
5. Have you ever received any awards for science teaching? If yes, what is that?
6. How do you feel when you know that you cannot teach students in the normal classroom?
7. What is the school procedure during Covid-19 situation?
8. Have you ever heard about blended learning? If yes, you think you follow this concept whether or not?
9. What do you blend? Between what method and method?
10. Can you assess yourself on educational technology use? What level? If low, how can you improve the skill of educational technology use?

Part 2: TPACK

1. When you know you have to teach student online, what is your first thing to do? (K4, K5)
2. Do you realize about the readiness of students to learn subject from home? How? (K4)
3. What is the big problem about that teaching and learning via online? How can you manage about those problems? (K4)
4. How did you organize a) teacher-student, b) student-student interaction/collaboration during on-site learning?
5. How did you organize a) teacher-student, b) student-student interaction/collaboration during on-line learning?
6. How did you plan a) on-site, b) on-line learning? Was there co-planning?
7. Can students use the educational technology? How do you know that and how do you help the students who lack of educational technology? (K4)

8. In what way, you think it is effective teaching for students during this situation? (K1-5)
9. Before teaching students about the livings, what do you plan and how? (K5)
10. In the class time, how do you begin the livings lesson? What educational technology you use? (K5)
11. How do you teach the content in that topic to students? What educational technology use? (K1)
12. About the scientific process, it is an important to study science. How do you teach the students to get the scientific process in blended learning situation? What educational technology is used for this situation? (K3)
13. What about the activities in the class, how do you design for students' participation in the class? (K2, 5)
14. what about learning materials you use between online and on site?
15. In what way that you can communicate to students after finishing the class, for example, if students have some questions about the content or work? (K2)
16. What is educational technology used frequently for teaching students? Give me some examples and describe them? (K1, 2, 3)
17. What about the project or work after finishing the lesson? How educational technology is related in this topic? (K2, 3)
18. If some students have a problem about use of technology, how can you cope with this? (K3, 4)
19. How do you assess the students' achievement? What way and anything else besides achievement such as behavior in class, skill use in the class? (K3)