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Author(s): Valtonen, Teemu; Sointu, Erkko; Kukkonen, Jari; Mäkitalo, Kati; Hoang, Nhi; Häkkinen, Päivi; Järvelä, Sanna; Näykki, Piia; Virtanen, Anne; Pöntinen, Susanna; Kostiainen, Emma; Tondeur, Jo

Title: Examining pre-service teachers' Technological Pedagogical Content Knowledge as evolving knowledge domains : A longitudinal approach

Year: 2019

Version: Published version

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Please cite the original version:

Valtonen, T., Sointu, E., Kukkonen, J., Mäkitalo, K., Hoang, N., Häkkinen, P., Järvelä, S., Näykki, P., Virtanen, A., Pöntinen, S., Kostiainen, E., & Tondeur, J. (2019). Examining pre-service teachers' Technological Pedagogical Content Knowledge as evolving knowledge domains : A longitudinal approach. Journal of Computer Assisted Learning, 35(4), 491-502. https://doi.org/10.1111/jcal.12353

ARTICLE

Examining pre-service teachers' Technological Pedagogical Content Knowledge as evolving knowledge domains: A longitudinal approach

Teemu Valtonen (D) | Erkko Sointu (D) | Jari Kukkonen (D) | Kati Mäkitalo (D) | Nhi Hoang (D) | Päivi Häkkinen (D) | Sanna Järvelä (D) | Piia Näykki (D) | Anne Virtanen (D) | Susanna Pöntinen (D) | Emma Kostiainen (D) | Jo Tondeur (D)

Faculty of Philosophy, University of Eastern Finland, Joensuu, Finland

Correspondence

Teemu Valtonen, Faculty of Philosophy, University of Eastern Finland, PO Box 111, 80101 Joensuu, Finland. Email: teemu.valtonen@uef.fi

Funding information Academy of Finland: Kulttuurin ja Yhteiskunnan Tutkimuksen Toimikunta, Grant/ Award Number: 273970

Abstract

The aim of this study is to outline the development and changes in pre-service teachers' technological pedagogical content knowledge (TPACK) assessments during the first 3 years in teacher education. Specifically, research was conducted at three measurement points over a 3-year teacher education period. The target group consisted of pre-service teachers (N = 148) from three Finnish universities. Results indicate a growth in confidence related to all TPACK areas during the research period. The strongest gains were in pedagogical content knowledge. In addition, the gains were larger in other areas related to pedagogical knowledge than areas related to technology or content knowledge. In areas without pedagogical knowledge, the changes were more moderate. In the discussion section, recommendations are provided on the potential of longitudinal use of the TPACK model to study and improve the development of pre-service teachers' TPACK.

KEYWORDS

ICT in education, latent growth curve modelling, longitudinal research, pre-service teachers, TPACK

1 | INTRODUCTION

The development of information and communication technology (ICT) has placed new expectations for current and future working life (Spector, 2010). These expectations relate to the working skills needed in the future, such as skills for collaboration, communication, creativity, problem solving, and critical thinking along with ICT skills and ICT literacy (cf. Voogt & Roblin, 2012), are currently considered as 21st century skills. This development creates new possibilities and expectations for

today's educational systems. Within the context of the Finnish educational system, especially the emphasized role of ICT, can be seen in the National Curriculum (Finnish National Board of Education, 2015) where ICT is seen both as a means for and a target of learning.

ICT is part of the everyday world of today's youth and pre-service teachers. Yet, acquiring the knowledge and skills to take advantage of ICT in pedagogically meaningful ways, to understand the benefits and potential of ICT for educational purposes is challenging (Lei, 2009; Valtonen et al., 2011). According to Sadaf, Newby, and Ertmer

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(2012), today's pre-service teachers have rather positive attitudes in general concerning the possibilities of ICT in education, still when it comes to concrete work, that is, actually using ICT in the classroom, attitudes are more reserved. In addition, based on a review by Brown and Englehardt (2017), it seems that pre-service teachers are often rather uncomfortable with integrating technology into teaching. This poses challenges for teacher education and according to Kirschner and Selinger (2003), teachers' inadequate skills and expertise are the bottleneck of taking advantage of ICT in education.

The technological pedagogical content knowledge (TPACK) model serves as a framework for studying pre-service teachers' knowledge related to the use of ICT in education based on three foundational knowledge areas: technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK) as well as three combined areas: technological pedagogical knowledge (TPK), technological content knowledge (TCK), and pedagogical content knowledge (PCK) (Mishra & Koehler, 2006). The TPACK framework is an actively used model, and according to Harris, Phillips, Koehler, and Rosenberg (2017), there are over 1,200 publications related to the TPACK framework. Despite the active use of the TPACK framework, there is a need for more longitudinal studies focusing on the development of TPACK (Hofer & Grandgenett, 2012; Valtonen et al., 2017; Voogt & Roblin, 2012) in order to support the understanding of pre-service teachers' TPACK during the teacher education process. The current study provides a longitudinal perspective on pre-service teachers' TPACK areas based on three measurements conducted during the first 3 years of teacher education (i.e., Bachelor of Arts [Education, 180 ECTS]). The aim is to examine pre-service teachers' yearly TPACK assessments and changes in assessments in the context of Finnish teacher education.

2 | BACKGROUND OF THE STUDY

Integration of ICT by (pre-service) teachers has been studied using different theoretical frameworks. One of these frameworks is the theory of planned behaviour (TPB) by Ajzen (1991). Based on the theory of planned behaviour framework, certain behaviour, in this case the use of ICT in education, is determined by attitudes, subjective norms, and perceived behavioural control related to behaviour. Another model used is the technology acceptance model by Davis (1989). According to the technology acceptance model, perceived usefulness of technology and ease of technology use are the main factors affecting the use of technology. Again, the unified theory of acceptance and use of technology by Venkatesh, Morris, Davis, and Davis (2003) suggests that acceptance of technology is affected by performance expectancy, effort expectancy, social influence, and facilitating conditions. There are several studies focusing on (pre-service) teachers' use of technology using the abovedescribed frameworks (see. Birch & Irvine, 2009; Teo, 2011; Teo & Tan, 2012; Valtonen et al., 2015). Still, it can be argued that these models are problematic in an educational context because the lack of areas focusing on pedagogy or content areas. In order to better highlight these, the association between technology, pedagogy, and content, the TPACK framework was used to frame this research.

2.1 | Defining TPACK

TPACK is a theoretical framework for studying and describing (preservice) teachers' knowledge related to pedagogically meaningful use of ICT in education (Koehler & Mishra, 2009). TPACK focuses on teachers' knowledge from three foundational perspectives: TK, knowledge related to various available technologies and their characteristics. TK also refers to interest in following the development of new technologies. CK refers to the central theories and concepts of the discipline. In addition, CK refers to the nature of the knowledge and the means of inquiry of the discipline (e.g., biology, mathematics, and history). PK refers to knowledge of learning processes and the readiness to support and guide the learning situation and learning process. PK is a generic form of knowledge related to the theories of learning.

These foundational areas combine as intermediate TPACK areas. TPK refers to an understanding of the nature of teaching and learning with technology: the benefits and disadvantages of different available technologies for certain pedagogical practices. PCK refers to knowledge of combining CK with PK in a way that makes the CK easy to understand and learn for others. TCK refers to how technology is used to further develop certain content areas (e.g., biology and mathematics) and how technology is used within a certain discipline. Koehler, Mishra, and Cain (2013) define TPACK as "an understanding that emerges from interactions amongst content, pedagogy, and technology knowledge [...] knowledge underlying truly meaningful and deeply skilled teaching with technology" (p. 66). The following table (Table 1) contain definitions with examples. The following table is modified based on TPACK review by Chai, Koh, and Tsai (2013).

2.2 | Exploring TPACK areas

Since its introduction, the TPACK framework has been actively used for various research purposes in both quantitative and qualitative studies (e.g., Voogt, Fisser, Roblin, Tondeur, & van Braak, 2013). Usually, TPACK is seen as a balanced entity of three overlapping knowledge areas. However, Doering, Veletsianos, Scharber, and Miller (2009) argue that TPACK should be seen as an evolving and multifaceted entity instead of a static representation comprising equally sized areas. Doering, Veletsianos, Scharber, and Miller (2009) also suggest that different areas of TPACK should not be assumed to be equal with respect to technology-dominant, pedagogy-dominant, or contentdominant knowledge bases. Furthermore, other studies have indicated that there are variations amongst pre-service teachers' TPACK (Koh & Chai, 2014; Valtonen, Kukkonen, Kontkanen, Mäkitalo-Siegl, & Sointu, 2018), indicating that instead of a static entity, TPACK needs to be seen as dynamic and developing. This poses challenges for studies describing the nature and development of pre-service teachers' TPACK areas.

In the PCK literature, Gess-Newsome (1999) discusses the nature of PCK in ways that are relevant to TPACK research. Gess-Newsome (1999) defined the integrative model of PCK, that is, a model where

TABLE 1 TPACK areas with examples

TPACK		
areas:	Definition	Example
ТК	Knowledge of how to use different ICT tools and applications.	Knowledge of how to use Web 2.0 tools (e.g., Wiki, Blogs, and Twitter).
РК	Knowledge of different teaching and learning approaches, theories of learning, and assessment methods without references to any specific content areas.	Knowledge of how to use inquiry-based learning method.
СК	Knowledge of subject matter, different discipline without considerations of teaching the subject matter.	Knowledge of mathematics, arts, literature, etc.
РСК	Knowledge of how to combine the CK and PK in order to make the learning of the subject matter easy, to make the content understandable.	Knowledge of examples and analogies to teach mathematics.
ТРК	Knowledge of how to take advantage of appropriate ICT for supporting certain teaching and learning approaches without considering subject matter.	Knowledge of <i>Kahoot</i> -application to activate students or <i>Padlet</i> -application for brainstorming.
ТСК	Knowledge of how to represent, research, and create the content with ICT without consideration of teaching. Knowledge of how ICT is used by content experts.	Knowledge of how to use content-specific simulations, navigation app in geography, or SPSS in statistics.
TPACK	Knowledge of how to combine different areas, how to use appropriate pedagogical approaches for certain content with appropriate ICT.	Knowledge of how to use the <i>Padlet</i> application for supporting students' brainstorming and sharing of ideas in a biology course.

Note. ICT: information and communication technology; PK: pedagogical knowledge; TK: technological knowledge; CK: content knowledge (science); PCK: pedagogical content knowledge; TPK: technological pedagogical knowledge; TCK: technological content knowledge; TPACK: technological pedagogical content knowledge.

PCK does not exist as its own domain; rather, teachers integrate separate areas of PCK during teaching. This means that separated areas can be taught and can develop separately. On the other extreme, Gess-Newsome (1999) define the transformative model of PCK, that is, a model where PCK is the only knowledge used whereas teaching and other areas are seen as latent sources, useful only when transformed into PCK. This discussion can also be seen in TPACK research (Voogt et al., 2013). According to Angeli and Valanides (2009), the question is whether TPACK is a unique body of knowledge itself, constructed from other latent forms of teacher knowledge as a "transformative view" or is TPACK a combination of other forms of teacher knowledge and enactment during teaching in an "integrative view?" In addition to these two extremes, in PCK research, Gess-Newsome (1999) define a position that can be considered also in the TPACK research, that is, in a position between the extremes by recognising the foundational knowledge areas and the actual PCK. According to Gess-Newsome (1999), "New knowledge gained through preparation programmes and teaching experiences increases the organization and depth of both foundational knowledge domains and PCK, though changes in one knowledge base will not necessarily result in changes in others" (p. 13). In the current study, seven TPACK areas were measured over time: TK, PK, CK, TPK, TCK, PCK, and TPACK.

2.3 | Cross-sectional and longitudinal studies focusing on TPACK

This section outlines the results from previous studies concerning (pre-service) teachers' TPACK areas. Schmidt et al. (2009) conducted

a pilot study in the United States in order to develop a TPACK measurement instrument. They also reported pre-service teachers' assessment of their TPACK. The target group consisted of 124 preservice teachers. Their results indicate that the pre-service teachers perceived their TPK as at the highest level and their level of PK and TPK as rather high as well. The areas assessed as the lowest were CK (science) and PCK. Overall, the variations amongst TPACK areas were rather small. Koh, Chai, and Tsai (2010) studied 1,185 firstsemester pre-service teachers' TPACK in Singapore. Their results indicate that pre-service teachers perceived their PK as the highest and CK as the lowest. Again, the differences between TPACK areas were small and all areas were perceived as above average, that is, no areas were assessed to be particularly low. Similarly, Archambault and Crippen (2009) studied 596 online teachers' TPACK in the United States. Their results indicate that pedagogical and TK and the combined PCK areas were rated highest. Areas of lower ratings were related to TK. Graham et al. (2009) measured in-service science teachers' TPACK (TPACK, TK, TPK, and TCK) as part of the teachers' professional development programme. The results indicate that before the programme, the highest-rated area was TK and TPK and the lowest-rated area was TCK. Nevertheless, the highest gains were in TCK. Although the challenging aspect revealed by these results is that they provide a rather contradicting picture of strong and weak TPACK areas; still, the important role of PK is highlighted in most of the studies.

In addition to cross-sectional studies, there are several studies focusing on the effects of different courses or other interventions for developing TPACK. Typically, these studies contain elements for studying TPACK-related areas before and after the intervention using both

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qualitative and quantitative methods (see Doering, Veletsianos, Scharber, & Miller, 2009; Graham, Borup, & Smith, 2012). Of the studies measuring the effects of different interventions, the number of longer-term longitudinal studies focusing on the development of TPACK is minimal. Gill and Dalgarno (2017) reported a 4-year longitudinal study conducted with qualitative methods in Australia. Their target group contained six pre-service teachers. Their results indicate differences in the development of TPACK and the importance of the role of teaching personnel and learning experiences with technology during teacher training (Gill & Dalgarno, 2017). In addition, initial ICT skills and pedagogy courses were shown to provide an important starting point for the development of TPACK. Hofer and Grandgenett (2012) conducted a three-semester (11 months) study focusing on pre-service teachers' TPACK development. This longitudinal study was conducted using mixed methods with four assessment points using self-report surveys as part of the master's in education initial licensure programme. The target group consisted of 17 preservice teachers. Based on the survey data, the largest gains were in integrated TPACK categories, especially TCK, TPK, and TPACK. The lowest gains were in TK, CK, and PK. In addition, the development of TK and CK was not straightforward, that is, the results at the second measuring point were lower than at the first measuring point. Apart from these results, longitudinal studies conducted with larger target groups following the gradual development of TPACK over longer periods, especially in the teacher training context, are scarce (Voogt & Roblin, 2012).

2.4 | Purpose of the study

According to Voogt and Roblin (2012), there is a need for longitudinal studies conducted over a longer time period and with a larger target group. The aim of this study is to provide new insight into the nature of pre-service teachers' developing TPACK. To meet these aims, we measure all seven areas of TPACK: the foundational areas (TK. PK. and CK) and their confidence with integrating them (PCK, TPK, TCK, and TPACK). This way of studying pre-service teachers' TPACK aligns with the ideas of Gess-Newsome (1999), recognizing the importance of separate foundational elements (PK, CK, and TK) and the intermediate areas (PCK, TPK TCK, and TPACK). We assume these insights are important for a better understanding of the way pre-service teachers' TPACK evolves. According to Tondeur et al. (2012) and Gao, Wong, Choy, and Wu (2011), the majority of pre-service and beginning teachers have difficulties using ICT in education. With yearly assessments, we are able to identify the confident and weak TPACK areas and possibly better understand the developments that lead to the challenges suggested by Tondeur et al. (2012) and Gao et al. (2011). Similarly, the visualization of separate TPACK areas provides perspectives for the discussion concerning the structure of TPACK, that is, whether the development is equal or if there are differences between TPACK areas over time and whether we need to acknowledge these development trends more thoroughly when discussing the structure of TPACK.

3 | RESEARCH METHOD

This longitudinal study focuses on the changes in pre-service teacher's TPACK assessments using three measurement points during the first 3 years in teacher education, that is, bachelor's degree studies. The following section outlines the main features of Finnish bachelor's degree studies in teacher education focusing on the elementary level, Grades 1 to 6.

3.1 | Context of the study—Finnish teacher education

Elementary-level teacher education in Finland includes a strong practical and research orientation providing teachers with competencies for continuous professional development. The aim is to educate reflective teachers who are capable of using research-based evidence in their everyday work (Kynäslahti et al., 2006). Teacher education studies focus on areas such as educational sciences, educational psychology, sociology, educational systems, and their meaning in society (Malinen, Väisänen, & Savolainen, 2012). Pre-service teachers are provided with skills to combine different content area knowledge with PK and become familiar with different technologies for teaching and learning. Pre-service teachers are expected to gain skills for critical and creative thinking and to conduct research activities independently. In practice periods, pre-service teachers integrate theoretical pedagogy and multidisciplinary subject studies by using a variety of teaching methods, inspiring learning environments and ICT.

Teacher education in Finland consists of a Bachelor of Arts (Education) degree (180 ECTS) and a Master of Arts (Education) degree (120 ECTS). The bachelor's degree covers the first 3 years of teacher education, that is, the area under focus in this longitudinal research. In Finland, a teacher must have master's degree in order to serve as a qualified teacher. At the universities participating in this study, the bachelor's degree contains the study units listed in Table 2, which is based on the curricula of the participating teacher education units. There are differences in the names of the units between universities

TABLE 2 Study units with the second sec	thin Finnish	teacher	education
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	University 1	University 2	University 3
Communication studies and orientation	15 ECTS	21 ECTS	20 ECTS
Basic studies in education	25 ECTS	25 ECTS	25 ECTS
Intermediate studies in education	45 ECTS	40 ECTS	38 ECTS
Multidisciplinary studies	65 ECTS	60 ECTS	60 ECTS
Minor subject studies	30 ECTS	34 ECTS	37 ECTS
Total	180 ECTS	180 ECTS	180 ECTS

Note. The Finnish university system follows the European Credit Transfer and Accumulation System (ETCS) of credit allocation. One year of full-time study requires approximately 1,600 hr of work, corresponding to 60 ECTS per academic year. Thus, one ECTS requires 26.7 hr of work. in Finland. Also, the extent of the courses in terms of credit points varies slightly.

Communication studies and orientation covers courses focusing on language skills and orientation for university-level studies. The studies also include courses addressing ICT in education. Basic and intermediate studies in education contains courses focusing on theoretical and philosophical areas of educational science. These units contain courses focusing on the basics of educational science, educational psychology, learning ethics, and so forth. In addition, the units contain courses on research methods in educational science, including both quantitative and qualitative methods. These units also include the first practice periods. Multidisciplinary Studies includes courses on all subjects taught in Grades 1 to 6 in elementary school, such as mathematics, geography, Finnish and literature, arts, music, and history. The aim of these courses is for pre-service teachers to learn to apply and combine the content areas of different disciplines with PK and to acknowledge the special features of teaching and learning content in certain disciplines. Courses within this unit provide examples and experiences of pedagogical practices within various content areas. These courses increasingly provide examples of how to integrate ICT in teaching these topics. The unit is compulsory in order qualify to teach pupils in Grades 1 to 6. In addition to these studies, bachelor's degree studies contain minor subject studies where pre-service teachers can choose studies based on their own interests. Courses in this unit provide deeper study in areas such as the arts, special education, and multicultural studies.

A number of different approaches to teaching and studying are used within Finnish teacher education. Some studies involve auditorium lectures with large numbers of participants; others are based on pre-service teacher's collaborative working in small groups. Courses might include self-study courses, book exams, portfolio assignments, demonstrations, and so forth, and vary from face-to-face courses to more blended courses and fully online courses. The role of ICT varies between universities and courses. All of the universities in this study provide their students with Internet access within campus buildings as well as cloud services (e.g., Office 365, GAFE, PedaNET) and personal online environments are provided for pre-service teachers.

3.2 | Respondents

The target group consists of three cohorts of pre-service teachers from three Finnish universities starting their studies in autumn 2014. The purpose and aims of the research were explained to all participants. Participation was voluntary. Data was collected using an online questionnaire. The total size of the three cohorts, representing the annual intake of new students for the three universities, was 365 pre-service teachers.

Research data were collected from the pre-service teachers' courses at three measurement points during 2014, 2015, and 2016 as follows: (a) permission for collecting the data was acquired from each teacher education department, (b) courses for the whole cohort were selected for data collection in each university, (c) researchers

explained the aims of the study to the participants in the selected courses, (d) informed consent was obtained from all participants. The total number of respondents at each measurement point, including both male and female respondents, varied from 267 to 209 (Table 3).

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Reasons for missing data include (a) opting out-not all pre-service teachers in the target group wished to participate, (b) not all preservice teachers in the target group participated in the courses where data was collected, and (c) not all pre-service teachers in the target group of accepted students started their studies in 2014 or some did not participate in studies during 2015 and 2016. To gain better results, the target group of pre-service teachers were also asked to participate via email and by personal phone calls. The data used in this study consists of 148 respondents who participated in the study at all three measurement points. The response rate was 40.5%. Missing data can affect the validity and reliability of the results. To avoid this, the results from the repeated measurement data (n = 148) were also compared with the cross-sectional data, that is, all other respondents each year not belonging to the target group of 148 pre-service teachers, using independent sample T-tests. No statistically significant (p > .05) differences could be found between the target group and those respondents who did not participate in all three measurements, that is, in the first year, 119 respondents; the second year, 80 respondents; and the third year, 61 respondents.

3.3 | TPACK-21 instrument

Measurements were conducted using a TPACK-21 questionnaire. Validity of the instrument has previously been tested using exploratory factor analysis (EFA; Valtonen, Sointu, Mäkitalo-Siegl, & Kukkonen, 2015) and confirmatory factor analysis (CFA; Valtonen et al., 2017). The construct validity of the measurement instrument was studied based on the current dataset by CFA. The CFA models of each time point were examined. In the first attempt, the fit indices of the models indicated that the models did not fit well with the values of comparative fit index (CFI), and Tucker-Lewis index (TLI) were lower than 0.900 and the values of root-mean-square error of approximation (RMSEA) and standardized root mean square residual (SRMR) ranged from 0.055 (TPACK Time 1) to 0.094 (TPACK Time 2). After checking the modification indices, we correlated the residual of some items to each other, the fits of the models have been improved and got acceptable fits. The values of CFI and TLI were greater than

TABLE 3 Sample descriptives

Three-yearly data of co teachers	hort 2014: 365 accepted	I new pre-service
T1: N = 267 (76% female – 24% male)	T2: N = 228 (75% female – 25% male)	T:3 <i>N</i> = 209 (79% female – 21% male)
All three measurements	n = 148 (listwise) (78% f	emale – 22% male)

*Note. T*1: measurement point 1 in 2014; *T*2: measurement point 2 in 2015; *T*3: measurement point 3 in 2016.

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0.900 and the values of RMSEA and SRMR were lower than 0.08. We also tested the univariable CFA models. The models were well fit with the values of CFI, and TLI were equal to 1.000 and the values of RMSEA and SRMR were 0.000. Due to the limited tables and number of words in this paper, the details of the validity process, the model fit indices of the CFA models, and the factor loadings of the CFA models at each time point are not reported in this paper.

Internal consistency for each scale using Cronbach's alpha (α) values are listed in Table 4 with example items. All α values were adequate at above 0.80 (e.g., Nunnally & Bernstein, 1994). The instrument contains 38 items using a six-point Likert scale (1 = *I need a lot of information about the measured area*; 6 = *I have strong knowledge of the measured area*). The areas of TPACK related to PK, that is, PK, TPK, PCK, and TPACK are grounded in 21ST century skills such as collaboration, problem solving, creative thinking, and critical thinking (see Voogt & Roblin, 2012). The aim of the instrument is that this way, we are able to better acknowledge different pedagogical approaches, for example, knowledge about how to support collaborative learning practices.

3.4 | Analysis of the data

Analysis of the data was conducted using SPSS and Mplus (version 7) software in the following phases. In the first phase, we tested the measurement invariance to assure the measurement is invariant across the time. We ran a set of increasingly constrained structural equation models (SEMs), and tested whether the difference between these models is significant. The model fit differences were determined by three goodness-of-fit indexes: the CFI (Bentler, 1990), the RMSEA (Steiger, 1990), and the SRMR (Bentler, 1995). The change criteria were –0.010 for CFI; 0.015 for RMSEA; and SRMR of 0.030 for metric invariance, 0.015 for scalar invariance (Chen, 2007; Cheung & Rensvold, 2002). The results of measurement invariance tests showed that although the full support of measurement invariance has not been

found, the partial measurement invariance was supported. Change in alternative fit indices of CFI (Δ CFI) ranged from 0.000 (metric model of TPK) to 0.009 (scalar model of TPK), the values of Δ RMSEA ranged from 0.001 (scalar model of PK, scalar model of PCK) to 0.008 (metric model of TK), and the values of Δ SRMR ranged from 0.000 (scalar model of PK, scalar model of TPK) to 0.013(scalar model of TCK). In the second phase, composite scores of individual TPACK-21 items were calculated (Table 4). In the third phase of the study, latent growth curve modelling (LGCM) was conducted using Mplus. LGCM is a class of SEMs and it allows obtaining the developmental trajectories of variables in longitudinal data. It also determines significant individual differences in the developmental trajectories by statistical significances of variances. In this phase of the analysis, seven LGCMs were fit using five fit indices: (a) the chi-square goodness of fit test, (b) CFI (Bentler, 1990), (c) the TLI (Tucker & Lewis, 1973), (d) SRMR (Bentler, 1995), and (e) RMSEA (Steiger, 1990). According to Hu and Bentler (1999), the recommended cut-off values for a well-fitting model need to be greater than 0.90 (for CFI and TLI) and below 0.08 (for RMSEA and SRMR). In addition, the descriptive statistics (mean value) were calculated for each TPACK area for each year (more details in Appendix A).

4 | RESULTS

The LGCM models were fitted separately for each variable. Well-fit was obtained for all variables except PCK and TPACK. The results indicate that the mean values for the different TPACK areas vary between 2.22 and 4.12, indicating variation in the pre-service teachers' perception of their knowledge, that is, from "need more knowledge" to "more confident perception". Moreover, none of the results indicated a strong knowledge of the TPACK areas. However, the tendency across the three measurement points was towards better confidence in the different TPACK areas.

TABLE 4 Number of items, internal consistency indicated by Cronbach's alpha (α), and example items of the TPACK-21 questionnaire

	Items	Cronbach α T1	Cronbach α T2	Cronbach α T3	Example item
РК	7	0.92	0.90	0.90	I know how to facilitate students' discussions during group work (3–5 students).
СК	4	0.88	0.82	0.85	I understand the basic theories and concepts of the natural sciences.
ТК	4	0.92	0.91	0.93	I am familiar with new technologies and their features.
PCK	6	0.95	0.93	0.92	In teaching the natural sciences, I know how to guide students' content-related problem solving in groups of 3-5 students.
ТСК	4	0.90	0.93	0.88	I understand ICT applications used by professionals in the natural sciences.
ТРК	6	0.95	0.93	0.94	In teaching, I know how to use ICT as a medium for sharing ideas and thinking together.
TPACK	7	0.96	0.94	0.94	In teaching natural sciences I know how to use ICT as a tool for sharing ideas and thinking together.

Note. ICT: information and communication technology; TK: technological knowledge; PK: pedagogical knowledge; CK: content knowledge; PCK: pedagogical content knowledge; TPK: technological pedagogical knowledge; TCK: technological content knowledge; TPACK: technological pedagogical content knowledge.

4.1 | Latent growth curve modelling

For most of TPACK's elements, the developmental trajectories provided good fits (Table 5; CFI >0.95, TLI >0.95, RMSEA <0.05, and SRMR <0.05 for PK, TK, CK, TPK, and TCK). For PCK, the LGCM did not fit well, CFI = 0.83, TLI = 0.50, RMSEA = 0.23, and SRMR = 0.08, indicating that the change of PCK was not significant. For the TPACK, the change in this element indicated poor fit, with two indices reporting an acceptable fit (CFI = 0.96, SRMR = 0.04) and the other two indices reporting a not-acceptable fit (TLI = 0.88, RMSEA = 0.15). Still, we report the PCK and TPACK in order to outline the changes in all TPACK areas. Reasons for a not-acceptable fit are discussed in more detail in the discussion section.

The latent growth curve trajectories of all the TPACK areas (Figure 1) show that assessments of all TPACK areas had increased, but the size of the changes still varied between TPACK areas (see Table 6). Table 6 shows that all the mean growth rates are significantly

TABLE 5	Model fit information of late	ent growth curve modelling
(N = 148)		

	Glo	bal fit in	dices				
Estimating	Chi mo	-square f del fit	test of				
model	df	x ²	р	CFI	TLI	RMSEA	SRMR
РК	1	0.081	0.776	1.000	1.042	0.000	0.006
ТК	1	0.192	0.661	1.000	1.010	0.000	0.007
СК	1	1.167	0.2799	0.999	0.996	0.034	0.017
РСК	1	9.101	0.0026	0.834	0.503	0.234	0.077
ТРК	1	0.073	0.7873	1.000	1.031	0.000	0.005
ТСК	1	0.726	0.3943	1.000	1.011	0.000	0.018
TPACK	1	4.141	0.0419	0.958	0.875	0.146	0.043

Note. CFI: comparative fit index; TLI: Tucker-Lewis index; RMSEA: rootmean-square error of approximation; SRMR: standardized root mean square residual; TK: technological knowledge; PK: pedagogical knowledge; CK: content knowledge; PCK: pedagogical content knowledge; TPK: technological pedagogical knowledge; TCK: technological content knowledge; TPACK: technological pedagogical content knowledge.



FIGURE 1 Latent growth curve trajectories [Colour figure can be viewed at wileyonlinelibrary.com]

positive. In the baseline, PK and CK had the highest starting points compared with other areas of TPACK, whereas TCK was at the lowest level. The slopes showed that the developments of TPACK areas were different over time. For example, PK, TPK, and TCK increased more than TK and CK (e.g., at the first measurement, the differences between PK and CK were minimal; PK M = 3.14, CK M = 3.03). At the third measurement, the difference was bigger, PK was perceived higher (M = 4.32) and CK was lower (M = 3.57).

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4.2 | Assessments of TPACK areas over time

In order to provide more insight into three measurements, the mean values of the TPACK assessments are presented in Table 7. At the beginning of teacher education, PK had the highest assessment score of all the TPACK areas (M = 3.14) and CK was scored at almost the same level (M = 3.03). TK, PCK, and TPK were scored close to each other with mean values varying between 2.83 and 3.90. The lowest scores were for TPACK (M = 2.54) and for TCK (M = 2.21). At the second measurement point in 2015, slight changes in the overall TPACK assessments were found. The highest scores were for PCK (M = 3.64) and PK (M = 3.62). The results indicate that TPK and CK were perceived as the next highest areas (TPK M = 3.37and CK M = 3.36). TPACK and TK were scored close to each other, at a slightly lower level (TPACK M = 3.19 and TK M = 3.12). Again, TCK gained the lowest assessment (TCK M = 2.72). At the last measurement point again, small changes in the TPACK assessments were found. The highest scores were, again, for PK (M = 4.13). PCK and TPK were assessed as the next highest close to each other (PCK M = 3.98 and TPK M = 3.83). CK and TPACK were perceived close to each other (CK M = 3.57; and TPACK M = 3.56). Finally, TK and TCK were the two weakest areas of all TPACK areas (TK M = 3.35 and TCK M = 3.10).

4.3 | TPACK changes

The changes between 2014 and 2015 were all positive. Altogether, the changes were larger between 2014 and 2015 than between 2015 and 2016 (Table 7). PK was the only variable with a greater change between 2015 and 2016. The greatest changes between 2014 and 2015 were for PCK (0.74) and for TPACK (0.65). Changes in TK and CK were the smallest, remaining below 0.40. The changes in the rest of the TPACK areas were between 0.60 and 0.40. The changes between 2015 and 2016 were more moderate. The greatest changes were for PK (0.51) and TPK (0.46). Again, the lowest gains were with CK and TK with an increase of only 0.21 for CK and 0.23 for TK. Other changes varied from 0.33 to 0.38.

Overall, during the 3 years of teacher training, the greatest increases in assessment rating were in the areas related to PK, especially PCK where the gain was from 2.90 to 3.98 (mean change 1.08, growth rate = 0.531) and TPACK with a gain from 2.54 to 3.57 (mean change 1.03, growth rate = 0.504). In addition, PK and TPK showed a strong increase. At the beginning and at the end of the studies, PK was

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TABLE 6	Parameter	estimates	for the	latent growt	h curve:	modelling	(N	= 148	3)
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Parameter	РК	тк	СК	РСК	ТРК	тск	ТРАСК
Means Intercept	3.137 (0.082)***	2.835 (0.098)***	3.057 (0.085)***	2.970 (0.082)***	2.885 (0.084)***	2.231 (0.081)***	2.597 (0.080)***
Slope	0.492 (0.044)***	0.264 (0.037)***	0.267 (0.045)***	0.531 (0.048)***	0.473 (0.045)***	0.447 (0.045)***	0.504 (0.045)***
Variances Intercept	0.706 (0.157)***	1.076 (0.200)***	0.716 (0.141)***	0.521 (0.146)***	0.658 (0.160)***	0.433 (0.162)**	0.482 (0.141)**
Slope	0.116 (0.062)	-0.046 (0.082)	0.117 (0.062)	0.120 (0.065)	0.096 (0.070)	-0.043 (0.083)	0.031 (0.068)
Correlation	-0.223	0.021	-0.122	-0.165 (0.082)*	-0.126 (0.086)	0.029 (0.096)	-0.058 (0.081)

Note. TK: technological knowledge; PK: pedagogical knowledge; CK: content knowledge; PCK: pedagogical content knowledge; TPK: technological pedagogical knowledge; TCK: technological content knowledge; TPACK: technological pedagogical content knowledge

*p _0.05. **p _0.01. ***p _0.001.

TABLE 7 Cross-sectional descriptive statistics (N = 148)

	2014 M	ΔΜ	2015 M	ΔΜ	2016 M
РК	3.15	0.48	3.63	0.49	4.12
СК	3.02	0.34	3.36	0.21	3.56
ТК	2.84	0.29	3.13	0.23	3.36
PCK	2.90	0.75	3.65	0.33	3.98
ТСК	2.22	0.51	2.72	0.38	3.10
ТРК	2.89	0.48	3.38	0.45	3.82
TPACK	2.55	0.63	3.19	0.36	3.55)

Note. M: mean; ΔM : change in the mean value between years; PK: pedagogical knowledge; CK: content knowledge; TK: technological knowledge; PCK: pedagogical content knowledge; TCK: technological content knowledge; TPK: technological pedagogical knowledge; TPACK: technological pedagogical content knowledge.

assessed as the highest TPACK area. Areas without pedagogy (TK, CK, and TCK) gained smaller growth. Altogether, the smallest changes of all TPACK areas were in TK and CK. During the first 3 years, the growth in TK scores evolved only from 2.83 to 3.35 (mean change.52, growth rate = 0.264); CK evolved from 3.03 to 3.57 (mean change 0.54, growth rate = 0.267).

5 | DISCUSSION AND CONCLUSION

The aim of the study was (a) to explore pre-service teachers' perceptions of their TPACK during the first 3 years of teacher education and (b) to investigate the changes of pre-service teachers' TPACK assessments over that period. The results indicate that teacher training seems to have a beneficial impact on TPACK; improvement was perceived to be gained in all of the TPACK areas studied, although the extent of the improvement differed between TPACK areas (see Table 7). Interestingly, the results indicate positive gains, especially in areas related to pedagogy. The strongest gains were in PCK, TPACK, and PK. The lowest gains were in CK and TK. These results indicate that teacher education in Finland provides strong support for the development of pre-service teachers' pedagogical thinking, providing pre-service teachers with stronger confidence in areas related to pedagogy than other TPACK areas.

Based on previous studies, it seems that pre-service teachers have difficulty finding ways to take advantage of ICT in teaching and learning in pedagogically meaningful ways (Lei, 2009; Valtonen et al., 2011). This aligns with the results of the first measurement of this study. In the first year, TPACK was perceived to be low, that is, the ability to use ICT in pedagogically meaningful ways in science learning was assessed as weak. However, the results show that improvement was perceived to be gained, most of all in TPACK and PCK. According to Ertmer and Ottenbreit-Leftwich (2010), the role of concrete examples of pedagogically meaningful ways of using ICT in education is vital for pre-service teachers to gain the knowledge and confidence to use ICT in education. Also, Tondeur et al. (2012) proposed that authentic learning situations combining theoretical knowledge with practice are important elements for pre-service teachers to gain understanding of pedagogically meaningful use of ICT in education. Furthermore, the role of teacher educators as role models for pre-service teachers is important (Tondeur et al., 2012). Based on the results by Tondeur et al. (2012) and Ertmer and Ottenbreit-Leftwich (2010), the role of multidisciplinary courses within Finnish teacher education is assumed to be important in this respect, and that such courses focusing on combining the content areas of different disciplines with PK and, typically, with pedagogically sound ICT practices, are crucial for development within these two TPACK areas.

In contrast to the changes in TPACK, the changes in TK remained modest during first 3 years of teacher education, posing challenges for developing teacher education. TK, that is, knowledge focusing on plain technology (see Koehler & Mishra, 2009), typically has a minor role within Finnish teacher education. The focus within Finnish teacher education is on combining areas of TPACK. More specifically, technology is studied as a tool to support learning certain content areas, meaning that examples of technology use are grounded in educational contexts. This raises questions about the role of TK and how pre-service teachers can be supported to reach an adequate level of TK. Further questions concern what constitutes an adequate level of TK and whether plain TK is needed or whether combined areas, such as TPK, should rather be considered. In addition, TCK is a challenging area for teacher education. In line with previous studies (see Graham et al., 2009), TCK was perceived as the lowest TPACK area within all measurements. The challenge with TCK may be the limited availability of content-specific technologies compared with more general-level technologies and software, such as tablet computers and office software. We assume that one reason for this is that content-specific technologies and software are typically rare and intended only for specific purposes, and the computers used in teacher education are not usually equipped with such technologies or software. Nevertheless, considering the rapidly increasing availability of a vast array of different applications for various purposes, this situation may well change in the coming years.

5.1 | Limitations and future studies

The LGCM provides an efficient method for assessing longitudinal data, the changes in pre-service teachers' TPACK assessments. However, the current study had some limitations, and as such provides opportunities for future research. The sample attrition in a longitudinal study is inevitable; in this study, the sample size remained acceptable (N = 148). Results indicated a poor fit for the PCK and TPACK. This poses questions pertaining to the reasons for these measures. Our assumption is that there are changes in the ways pre-service teachers assess their TPACK areas during the first 3 years in teacher education and the assessments may not be consistent during that period. Two areas with poor fit indexes were those with the highest gains, and this poses questions concerning the methods used, that is, there is a need for using different approaches for modelling the seven elements of TPACK for longitudinal settings. In addition, an interesting approach would be adding a fourth measurement point, to study whether that affects the fit levels. Also, because of limited space, the more detailed descriptions and tables focusing on the TPACK-21 instrument and especially measurement invariance will be further studied and reported in future articles.

Altogether, these challenges highlight the complex nature of the TPACK framework with seven areas. Within previous studies, the measuring and modelling of TPACK using SEM has posed difficulties (Archambault & Barnett, 2010; Chai, Koh, Tsai, & Tan, 2011). Still, we assume that five out of seven elements with good fit is a good result and a good starting point for future studies modelling the growth trajectories on TPACK within teacher education. We assume that in the future, the longitudinal research approaches will pose new challenges for the instruments. In this case, in the future there will be a need for further development of the TPACK-21 instrument. For a specific future addition, an important area would be the introduction of similar longitudinal methods for in-service teachers, to study whether in-service teachers' TPACK changes over time.

The results outlining changes in TPACK areas and in differences between TPACK areas led to further questions concerning the factors affecting the changes and differences between TPACK elements. These results call for further research into the effects of different courses on changes in pre-service teachers' TPACK. Several studies have been conducted on the effects of different courses on technology in education (e.g., Doering, Veletsianos, Scharber, & Miller, 2009; Graham, Borup, & Smith, 2012). However, instead of focusing specifically on educational technology, we consider it important to study the effects of other "normal" courses in teacher education, such as those focusing on educational science, educational psychology, and learning ethics. It would be beneficial to identify what areas pre-service teachers specifically "grasp" within these courses taught using normal technology in pedagogically meaningful ways, what areas pre-service teachers pay attention to, and how they affect TPACK. This would provide important information for designing teacher education courses and curricula to better meet the needs of pre-service teachers in developing TPACK.

In addition, it is important to outline the differences amongst preservice teachers based on their TPACK assessments and what kinds of subgroups we can identify based on their TPACK. This would again provide us with more information for seeking ways to support the development of pre-service teachers' TPACK and meeting the needs of pre-service teachers within different TPACK profiles. Finally, the current study is limited to the data gained using the TPACK-21 selfassessment questionnaire. An important aspect for future investigation would be to expand the methods used for assessing TPACK (Krauskopf & Forssell, 2018) and to deepen these results using qualitative methods, such as lesson plans and interviews that would provide deeper insight into the nature and development of pre-service teachers' TPACK.

6 | CONCLUSION

The key conclusions arising from this study are (a) that teachertraining institutions in Finland have a beneficial impact on the development of pre-service teachers' TPACK and (b) that the TPACK model has potential as a vehicle for improvement in the complex process of preparing future students for ICT integration. Specifically, this longitudinal approach provides an insight into the progress of the different TPACK areas and possible changes occurring in relation to each other. Better understanding of the changes in pre-service teachers' TPACK is needed to provide stepping stones to support them in the development of specific areas of TPACK.

ORCID

Teemu Valtonen () https://orcid.org/0000-0002-1803-9865 Erkko Sointu () https://orcid.org/0000-0003-4001-7264 Jari Kukkonen () https://orcid.org/0000-0002-9448-4784 Kati Mäkitalo () https://orcid.org/0000-0003-2786-512X Nhi Hoang () https://orcid.org/0000-0002-4114-1868 Päivi Häkkinen () https://orcid.org/0000-0001-6616-9114 Sanna Järvelä () https://orcid.org/0000-0001-6623-3668 Piia Näykki () https://orcid.org/0000-0002-2931-704X Anne Virtanen () https://orcid.org/0000-0001-9846-090X Susanna Pöntinen () https://orcid.org/0000-0001-9846-090X Susanna Pöntinen () https://orcid.org/0000-0003-1997-457X Jo Tondeur () https://orcid.org/0000-0002-3807-5361

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How to cite this article: Valtonen T, Sointu E, Kukkonen J, et al. Examining pre-service teachers' Technological Pedagogical Content Knowledge as evolving knowledge domains: A longitudinal approach. J Comput Assist Learn. 2019;35:491-502. https://doi.org/10.1111/jcal.12353

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MEANS, STANDARD DEVIATIONS, AND CORRELATION BETWEEN TPACK CONSTRUCTS IN THREE DIFFERENT MEASUREMENT POINTS

																						L
	Σ	SD	PK1	PK2	PK3	TK1	TK2	TK3	CK1	CK2	CK3	PCK1	PCK2 F	CK3]	rpk1 T	PK2 TI	PK3 TC	CK1 TC	K2 TCK	3 TPACK:	1 TPACK2	500
PK1	3.14	(1.02)																				
PK2	3.61	(0.94)	0.51**																			ar C
PK3	4.13	(0.81)	0.32**	0.36**																		, , ,
TK1	2.83	(1.22)	0.22**	0.15	0.14																	
TK2	3.12	(1.21)	0.16	0.26**	0.11	0.75**																ηh
TK3	3.35	(1.27)	0.18*	0.22**	0.29**	0.73**	0.69**															au
CK1	3.03	(1.10)	0.44**	0.31**	0.22**	0.32**	0.33**	0.36**														
CK2	3.36	(0.92)	0.35**	0.51**	0.30**	0.33**	0.42**	0.44**	0.59**													~3
CK3	3.57	(0.99)	0.29**	0.46**	0.48**	0.29**	0.34**	0.49**	0.44**	0.65**												213
PCK1	2.90	(1.01)	0.72**	0.42**	0.21*	0.21*	0.18*	0.21*	0.54**	0.31**	0.20*											
PCK2	3.64	(0.88)	0.52**	0.76**	0.34**	0.21**	0.28**	0.25**	0.36**	0.62**	0.42**	0.42**										
PCK3	3.98	(0.82)	0.34**	0.34**	0.76**	0.18*	0.13	0.36**	0.32**	0.42**	0.65**	0.23**	0.38**									Cu
TPK1	2.88	(1.06)	0.52**	0.37**	0.23**	0.54**	0.43**	0.46**	0.43**	0.27**	0.22**	0.61**	0.33** C	.25**								
TPK2	3.37	(1.00)	0.29**	0.48**	0.34**	0.51**	0.58**	0.52**	0.22**	0.45**	0.37**	0.27**	0.57** C	.39** 0	.50**							
TPK3	3.83	(0.95)	0.23**	0.29**	0.52**	0.45**	0.39**	0.65**	0.35**	0.44**	0.58**	0.27**	0.29** C	.59** 0	.40** 0.	.50**						
TCK1	2.21	(1.04)	0.50**	0.44**	0.31**	0.36**	0.34**	0.33**	0.50**	0.39**	0.43**	0.58**	0.36** C	.34** 0	.64** 0.	35** 0.3	39**					
TCK2	2.72	(1.01)	0.29**	0.34**	0.23**	0.37**	0.47**	0.42**	0.41**	0.46**	0.32**	0.37**	0.44** C	.22** 0	.36** 0.	48** 0.3	35** 0.4	**				
TCK3	3.10	(1.06)	0.27**	0.39**	0.49**	0.29**	0.31**	0.44**	0.24**	0.38**	0.59**	0.23**	0.28** C	.54** 0	.37** 0.	43** 0.0	65** 0.4	l5** 0.4	1**			
TPACK1	2.54	(1.01)	0.63**	0.41**	0.28**	0.41**	0.37**	0.33**	0.46**	0.28**	0.28**	0.73**	0.37** C	.27** 0	.79** 0.	44** 0.3	37** 0.7	76** 0.4	7** 0.36*	*		
TPACK2	3.19	(0.60)	0.42**	0.58**	0.31**	0.39**	0.47**	0.44**	0.28**	0.49**	0.39**	0.41**	0.71** C	.35** 0	.45** 0.	.80** 0.4	44** 0.3	38** 0.6	0.38 [*]	·* 0.47**		
TPACK3	3.56	(0.93)	0.31**	0.35**	0.54**	0.35**	0.30**	0.55**	0.34**	0.42**	0.63**	0.26**	0.33** C	.66** 0	.38** 0.	.46** 0.8	82** 0.4	18** 0.3	2** 0.75*	·* 0.39**	0.45**	
Vote. M: m edge; TCK:	ean; <i>SD</i> : technol · ·	t standar logical co	d deviati	on; PK: p nowledge	edagogic ;; TPACK	al knowl : technol	edge; TK: logical pe	technolo dagogical	gical kno content	wledge; C knowledε	:K: conter ge. Numb	nt knowle er after T	dge (scier PACK are	ıce); PCK :a indicat	: pedagog es measu	gical conte rement po	ent knowl oint.	edge; TPK	: technolog	gical pedago	gical knowl-	
Correlaui	on is sig	niticant ,	at the U.	UT IEVEI.																		

*Correlation is significant at the 0.05 level.