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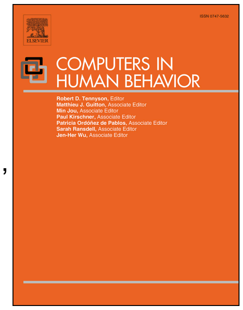

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The Importance of Attitudes Toward Technology for Pre-Service Teachers' Technological, Pedagogical, and Content Knowledge: Comparing Structural Equation Modelling Approaches

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Abstract

A large body of literature suggests that attitudes toward technology and its educational use are important determinants of technology acceptance and integration in classrooms. At the same time, teachers' Technological, Pedagogical, and Content Knowledge (TPACK) facilitates the meaningful use of technology for educational purposes. Overall, attitudes toward technology and TPACK play a critical role for technology integration and have been in the focus of many empirical studies. Albeit the attention that has been paid to these two concepts, their relation has not been fully understood. The present study contributes to the advancement of this understanding by examining the relations between three core technology attitudes (i.e., general attitudes towards ICT, attitudes towards ICT in education, and ease of use) and TPACK self-efficacy beliefs, based on a sample of N = 688 Flemish pre-service teachers in 18 teacher-training institutions. Using a variety of structural equation modeling approaches, we describe the TPACK-attitudes relations from multiple perspectives and present a substantive-methodological synergism. The analyses revealed that the attitudes toward technology and TPACK self-beliefs were positively related; yet, differences across the attitudes and TPACK dimensions existed, pointing to the delineation of general *and* educational perspectives on the use of ICT.

Keywords: Attitudes toward technology; Latent variable models; Substantive-methodological synergism; Teacher education; Technological, pedagogical, content knowledge (TPACK)

The Importance of Attitudes Toward Technology for Pre-Service Teachers' Technological, Pedagogical, and Content Knowledge: Comparing Structural Equation Modelling Approaches

Attitude is a little thing that makes a big difference.

– Winston Churchill (1874-1965)

Introduction

There is no doubt that attitudes matter. In fact, they determine how people perceive situations, feel about them, and behave (Ajzen, 1996; Fazio & Roskos-Ewoldsen, 2005; Heider, 1946). This almost deterministic relationship between attitudes and behavior does not only play a role in everyday-life situations—it surfaces in classroom situations as well (OECD, 2016; Richardson, 1996). For instance, the advancement of new technologies in the twenty-first century and the resultant curricular focus on digital problem-solving skills almost necessitates the use of technology in educational setting (Ferrari, 2013; Siddiq, Hatlevik, Olsen, Throndsen, & Scherer, 2016; van Laar, van Deursen, van Dijk, & de Haan, 2017)s. At the same time, the core actors in educational systems—students and teachers—must be prepared for this inexorable development. This has brought to front teachers' attitudes toward technology as determinants of the acceptance and adoption of ICT for teaching and learning purposes. A large body of research indeed confirms that ICT attitudes are positively related to the acceptance and use of ICT in classrooms (Imtiaz & Maarop, 2014; Straub, 2009; Teo & van Schaik, 2012).

At the same time, considerable attention has been paid to teachers' professional competences for ICT integration in classrooms. This attention manifested in the development of a framework that lays out a set of knowledge domains teachers should acquire to integrate and use technology meaningfully (Koehler, Mishra, Kereluik, Shin, & Graham, 2014; Mishra & Koehler, 2006)—a conceptual framework referred to as Technological, Pedagogical, and

Content Knowledge (TPACK) describing the knowledge base for teachers to effectively teach with technology. This framework emphasizes the interactions between content, pedagogy and technology, and was derived from Shulman's (1987) well-known concept of pedagogical content knowledge. Next to ICT attitudes, TPACK and teachers' self-efficacy beliefs in it also determine technology acceptance (Gil-Flores, Rodríguez-Santero, & Torres-Gordillo, 2017; Mei, Brown, & Teo, 2017). Although TPACK and attitudes may play a similar role in technology acceptance, their relation has scarcely been explored. One of the reasons for this research gap may lie in the methodological challenges associated with the measurement of attitudes toward technology: Different dimensions of attitudes, such as attitudes toward the general use of ICT, attitudes toward the educational use of ICT, and attitudes toward the ease of ICT use – just to name a few – are often highly correlated and thus hardly distinguishable (Baş, Kubiatko, & Sünbül, 2016; Bong, 2001; Hernández-Ramos, Martínez-Abad, García Peñalvo, Esperanza Herrera García, & Rodríguez-Conde, 2014). Such challenges compromise the analysis of TPACK-attitudes relations and may thus lead to erroneous interpretations (Marsh, Dowson, Pietsch, & Walker, 2004). Consequently, a synergism between the substantive concept of ICT attitudes and methodological approaches is needed to address these challenges.

The present study responds to this call as it analyzes the data obtained from a Flemish sample of N = 688 student teachers' who reported on their TPACK self-efficacy and three core attitudes toward ICT. Performing structural equation modeling, we report on the TPACK-attitude relations from different perspectives and thereby demonstrate how a synergism between a substantive research question that is relevant to the fields of teacher education and educational technology *and* methodological approaches helps to circumvent ubiquitous findings. This study further exemplifies how structural equation models can be used to describe the connection between attitudes toward ICT and TPACK.

Theoretical Framework

This section is organized as follows: We first review the conceptualization and distinction of different attitude dimensions to emphasize their commonalities and thus strong empirical relations. Second, we introduce the TPACK framework and describe approaches to the measurement of TPACK self-efficacy. The final section brings together these two concepts—attitudes toward ICT and TPACK—and presents the extant literature on their empirical link.

Attitudes toward ICT

Research on pre- or in-service teachers' attitudes toward ICT has a longstanding tradition since the emergence of educational technology. This tradition was primarily motivated by the question regarding which factors might determine teachers' intentions to use and the actual use of ICT in classrooms (Mumtaz, 2000; Straub, 2009; Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011) – indeed, attitudes toward ICT are among these factors (Imtiaz & Maarop, 2014; Marangunić & Granić, 2015).

Attitudes toward ICT have been conceptualized in several ways, and the existing body of research proposes a range from narrow to broad conceptualizations. Focusing on the correspondence between attitudes and behavior from a domain-general perspective, Ajzen and Fishbein (1977) referred to "attitudes" as "a person's […] evaluation of the entity in question" (p. 889). These entities represent "some aspect[s] of the individual's world, such as another person, a physical object, a behavior, or a policy" (p. 889). In the context of educational technology, this broad definition of attitudes refers to the use of ICT, ICT-related material (e.g., learning environments, digital textbooks), or teaching practices. Zhang, Aikman, and Sun (2008) specified this definition further and distinguished between two core aspects: *behavior*-oriented ICT attitudes and *objec*t-oriented ICT attitudes. The former describes a person's evaluation in favor or disfavor of ICT as an object; the latter describes a person's evaluation of the (anticipated) performance of a specific behavior, such as the use of ICT for teaching and learning. This delineation can almost be simplified to the distinction between *technological* and *educational* aspects of ICT use (Scherer, Siddiq, & Teo, 2015). Zhang et al. (2008) found empirical support for this delineation and argued that attitudes toward ICT as a behavior are better predictors of the intention to use ICT than object-oriented attitudes.

In fact, existing models of technology acceptance incorporated the behavioral components of ICT attitudes to predict behavioral intentions and a person's actual behavior, such as the use of ICT for specific purposes (Venkatesh, Morris, Davis, & Davis, 2003). Even further, the technology acceptance model (TAM)—a model that describes the interplay between factors that explain variation in teachers' behavioral intention and their actual ICT use—proposes that attitudes toward ICT are *the* critical predictors of ICT use, next to perceived usefulness and perceived ease of use (Marangunić & Granić, 2015). This model has gained considerable attention in educational technology, because it provides possible explanations why teachers might or might not make use of technology (Teo, 2008). Moreover, the latter two represent sources of ICT attitudes and complete the list of motivational variables within the core of the TAM (Turner, Kitchenham, Brereton, Charters, & Budgen, 2010). Given this close relation among ICT attitudes, perceived usefulness, and ease of use, some authors consider them to be facets of teachers' *general attitudes* toward ICT (Kreijns, Vermeulen, Kirschner, Buuren, & Acker, 2013; Teo, 2008; Woodrow, 1991).

Concerning the measurement of ICT attitudes, the large body of empirical studies relies on in-service or pre-service teachers' self-reports (Imtiaz & Maarop, 2014; Marangunić & Granić, 2015), which often capture different aspects of ICT attitudes, such as attitudes toward the educational use or general use of ICT. These facets are often highly correlated as they rely on the same trait, that is, teachers' evaluations of ICT as an object or a behavior (Baş et al., 2016; Fraillon, Schulz, Friedman, Ainley, & Gebhardt, 2015; Hernández-Ramos et al., 2014). For instance, although Zhang et al. (2008) hypothesized the distinction between object-and behavior-oriented attitudes, the empirical results showed substantially high correlations between different measures of these two aspects, ρ = .77-.85. Empirical studies that differentiated between core ICT attitudes—general attitudes toward ICT, perceived usefulness, and perceived ease of use—confirmed these strong relations (Pynoo et al., 2011; Scherer et al., 2015; Teo, Lee, & Chai, 2008; Teo, Lee, Chai, & Wong, 2009). Considering these correlations, it is not surprising that attitudes toward ICT as a behavior predict behavioral intentions, whereas attitudes toward ICT as an object do not. More specifically, the high correlations among attitudes might affect the structural parameters in the regression model–a phenomenon referred to as "multicollinearity" (Farrar & Glauber, 1967). In a similar context, Marsh, Dowson, et al. (2004) argued that this poses a severe issue which might lead to uninterpretable results or even misleading conclusions. Among others, Johnson (2000) addressed multicollinearity by a weighting procedure which allows researchers to disentangle the unique contributions of predictors to explaining variation in the outcome variable. Thomas, Zumbo, Kwan, and Schweitzer (2014) extended this procedure and found alternative approaches to dealing with multicollinearity—overall, methodological research provides a range of tools to obtain more accurate regression parameters and standard errors when predictor variables are highly correlated (Marsh, Dowson, et al., 2004). The issue that different facets of ICT attitudes are highly correlated is critical and demands researchers' methodological attention.

TPACK

Teachers' TPACK conceptualizes knowledge domains that are relevant for teachers to implement technology in teaching and learning processes (Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2013). This framework proposes a set of *general* knowledge domains (e.g., content knowledge [CK], pedagogical knowledge [PK], and pedagogical content knowledge [PCK]) and *technological* knowledge domains (i.e., technological knowledge

[TK], technological pedagogical knowledge [TPK], technological content knowledge [TCK], and technological pedagogical content knowledge [TPCK]). TPACK was derived from the well-known PCK model (Shulman, 1987), which considers PCK a unique feature that qualifies the teacher profession: teachers are able to integrate domain knowledge with appropriate pedagogical approaches so that students are able to understand the subject. TPCK has a similar notion, it adds technological knowledge as in indispensable part of the teacher profession. TPACK was embraced by both scholars and practitioners. Although TPACK is an intuitive concept that easily resonates with practitioners, it is considered a complex concept by many scholars and gives rise to academic discourse (Voogt, Fisser, Tondeur, & van Braak, 2016). Hammond and Manfra (2009) conceive TPACK as a common language for discussing the integration of technology in education: "our model of giving-prompting-making is intended to clarify the relationship between PCK and technology within TPACK" (p. 174). In their opinion teachers first determine how they teach specific content (PCK), and then consider the use of technology.

Figure 1 exhibits the relations among the different knowledge domains, as they were originally conceptualized. In the context of technology integration, the so-called "T-dimensions"—representing the technological part of the TPACK framework—have been in the main interest of teacher educators and researchers, and are conceptualized as follows (e.g., Chai, Koh, & Tsai, 2013; Koehler et al., 2014; Koh, Chai, & Tsai, 2013; Schmidt et al., 2009): *TPCK* – "knowledge about the complex relations among technology, pedagogy, and content that enable teachers to develop appropriate and context-specific teaching strategies" (Koehler et al., 2014, p. 102); *TPK* – knowledge about the use of ICT to implement instructional practices, principles, and strategies; *TCK* – knowledge about how the subject matter can be represented with the help of technology; *TK* – knowledge of and about technology. Whereas TPCK, TCK, and TPK represent the technological counterparts to

Shulman's general knowledge domains, TK has its own position within the framework in that it refers to knowledge about technological content inside or outside of teaching and learning contexts (Schmidt et al., 2009).

The conceptual distinction between TK and the other TPACK domains is an important characteristic of the framework and has recently been substantiated in empirical studies of in- and pre-service teachers (Authors, 2017a; Kaya & Dağ, 2013). More specifically, in studies using the TPACK framework as a blueprint for the design of assessments, dimensionality analyses indicated that TK can be differentiated from the other TPACK aspects (Koehler et al., 2014). This finding also surfaced in the result that the more pedagogically- and content-oriented knowledge domains (i.e., TPCK, TCK, and TPK) were highly related with correlations as high as .90 (Chai, Koh, & Tsai, 2016; Koh et al., 2013; Sahin, 2011). The "high degree of correlation between the subscales of TPACK raise questions about the extent to which the components of TPACK are, in fact, separate components" (Koehler et al., 2014, p. 102), and camouflage the boundaries between these knowledge domains (Graham, 2011). This observation poses a methodological challenge, especially when researchers want to make use of the TPACK framework as an assessment framework to extract its dimensions, or more precisely the corresponding subscale scores, as predictors of technology integration. Two recently published studies addressed this challenge: Mei et al. (2017) examined the role of TPACK for technology acceptance in the context of computer-assisted language learning and determined the extent to which TPACK—as an indicator of teachers' pedagogical capabilities to use technology for educational purposes—predicted technology acceptance. The authors adapted an existing TPACK self-report measure that focused on the technology-related dimensions (Koh et al., 2013) and created an overall TPACK score to circumvent possible issues associated with multicollinearity. In another study, Authors (2017a) established that a general TPACK factor (gTPACK) and a specific TK factor can be differentiated with the help of complex factor models. In their study, the authors addressed the issue of highly correlated TPACK dimensions by extracting what is common to all dimensions (gTPACK) and what is unique to some of them (specific TK). This study was also based on a self-report measure of the technology-related TPACK dimensions. Nevertheless, some researchers disentangled different profiles of pre-service teachers using the entire TPACK framework, including its non-technical dimensions (Sointu et al., 2017). This diversity of findings shows that the use of the TPACK framework as an assessment framework that distinguishes between knowledge dimensions may be problematic (Koehler et al., 2014).

A possible explanation for the high correlations among the technological dimensions may lie in the way they are measured. Most empirical TPACK studies rely on in- or pre-service teachers' self-reports, focusing on the extent to which they feel competent in the knowledge domains (Chai et al., 2016; Koehler et al., 2014; Voogt et al., 2013). These self-reports reflect on self-efficacy beliefs – individuals' perceptions of their capabilities to achieve certain goals or to perform certain behaviour (Bandura, 1997), yet not actual performance. Authors (2017a) have listed several reasons for the use of self-efficacy measures of TPACK. Independent of the knowledge domain, these indicators target the same belief system, that is, one's self-beliefs about specific knowledge, skills, and competences, high correlations among them are likely (Marsh, Dowson, et al., 2004). The fact that TPACK self-reports measure self-efficacy—an important facet of motivation (Schunk, 1991)—is vital to consider when interpreting the TPACK-attitudes relations.

TPACK-Attitudes Relations

Integrating the two perspectives – that of attitudes toward ICT and that of TPACK – poses the question about how these two concepts are related. In fact, knowledge about these relations may help researchers to develop existing models of technology acceptance and

TPACK further and could provide teacher educators with valuable information about what to emphasize to enhance TPACK.

Recently, several attempts have been made to integrate TPACK and attitudes toward ICT by extending the technology acceptance model. For instance, Mei et al. (2017) assessed TPACK by self-efficacy measures and considered it an external variable predicting perceived usefulness, ease of use, and behavioral intentions to use ICT next to computer self-efficacy. The authors found positive relations between an overall TPACK score and perceived usefulness ($\rho = .41$), and ease of use ($\rho = .78$). Moreover, Liu (2011) identified a positive effect of TPACK on attitudes ($\beta = .31$) and found support for direct as well as indirect effects on the usage intentions. Focusing on traditional and innovative forms of ICT use, Teo, Milutinović, Zhou, and Banković (2016) and Avidov-Ungar and Eshet-Alkalai (2011) confirmed the positive and significant relations between overall TPACK, perceived usefulness, and general ICT attitudes. An element common to these studies is that both TPACK and attitudes were represented by overall scores as indicators, without specifying their specific facets. Finally, some researchers argue that the development of TPACK or self-efficacy in teaching with ICT cannot be achieved independent of their attitudes toward ICT (Koh & Divaharan, 2011; Sointu et al., 2017; Tondeur, Siddiq, Scherer, & Baran, 2017). Overall, these findings provide ground for hypothesizing positive TPACK-attitudes relations and, at the same time, emphasize the need for a more fine-grained investigation of these relations which differentiate between different facets of both TPACK and attitudes toward ICT.

The Present Study

Considering the relation between teachers' TPACK and their attitudes toward ICT, this study serves two main purposes: First, it is aimed at examining the TPACK-attitudes relations with a TPACK measure that captures the T-dimensions of TPACK and a measure that captures three core attitudes toward ICT (i.e., general attitudes toward ICT, attitudes toward the educational use of ICT, and perceived ease of ICT use). Instead of representing TPACK and ICT attitudes as unidimensional constructs, we distinguish between different facets to obtain detailed information about how the two constructs are related. This multidimensional perspective may provide important insights as to how *specific* TPACK dimensions relate to *specific* attitudes dimensions. Substantive knowledge about these empirical relations contributes to the advancement of technology acceptance and TPACK models (Chai et al., 2016; Mei et al., 2017).

Second, the paper showcases the usefulness of different structural equation modeling approaches to describe the TPACK-attitudes relations. These approaches address the methodological issue of multicollinearity encountered in studies that use highly correlated motivational measures, such as attitudes toward ICT. As Marsh, Dowson, et al. (2004) argued, multicollinearity might leave researchers with erroneous conclusions on relations among variables. This paper presents the application of three approaches to circumvent these methodological fallacies within a structural equation modeling framework: (1) Correlated-traits models with and without parameter constraints; (2) Second-order factor models; (3) Nested-factor models. These transferable approaches provide researchers in the field of educational technology with tools to describe the relations among highly correlated constructs from different perspectives. We will further discuss the advantages and disadvantages of each approach to help researchers decide on the most appropriate approach for their studies. The key research question for the present study reads:

To what extent are pre-service teachers' attitudes towards ICT related to the T-dimensions within the TPACK framework (i.e., TPCK, TCK, TPK, and TK)?

Method

Sample and Procedure

The data underlying the present study were obtained from a sample of *N* = 688 pre-service teachers in their final year of teacher training (age: *M* = 25.0 years, *SD* = 7.7 years). Initially, we contacted the heads of several teacher-training institutions in Flanders, the Dutch-speaking part of Belgium, eighteen of which provided sufficient data.[1] Although the proportion of female pre-service teachers was substantially high (74.0%), this distribution was representative of the body of pre-service teachers at the time of the study (2014-15). Most of the 688 pre-service teachers had obtained a Bachelor’s degree in higher education (57.7%); 42.3% had obtained a specific teacher-training degree from universities, colleges, or adult learning centers. There was no restriction on the subject domains pre-service teachers specialized in. All participants completed an online survey that contained questions concerning their TPACK self-efficacy beliefs, attitudes toward ICT, the perceived support at their teacher-training institution, and background information (e.g., age, gender, subject domains). Study participation was voluntary and completely anonymous.

Measures

TPACK. An adapted Dutch version of the Schmidt et al.’s (2009) TPACK scales was used to assess pre-service teachers’ self-beliefs in the technology dimensions (TPCK, TCK, TPK, and TK). This version has been evaluated in several studies and showed evidence of reliability and construct validity (Authors, 2017a). Pre-service teachers were asked to indicate their agreement with statements that presented aspects of their self-efficacy beliefs in the four T-dimensions. A five-point response scale was administered that ranged from 0 (*I completely disagree*) to 4 (*I completely agree*). Supplementary Material S1 presents this scale in detail.

[1] The data used in the present study formed the basis for previously published works that focused on: (a) the validation of the TPACK-measure across gender (Authors, 2017a); (b) the psychometric evaluation of the so-called SQD-scale (Authors, 2016); (c) the identification and interpretation of motivational ICT profiles (Authors, 2017b).

Attitudes toward ICT. Three core attitudes toward ICT were assessed, namely general attitudes toward ICT, attitudes toward the educational use of ICT, and perceived ease of ICT use (e.g., Teo et al., 2008). The "General attitudes toward ICT" (GATT) scale contained five items, which included statements about general interest, pleasure, and usefulness of ICT (e.g., "The use of ICT is useful to me"; Evers, Sinnaeve, Clarebout, van Braak, & Elen, 2009). The "Attitudes toward the educational use of ICT" (EDATT) scale referred to the perceived usefulness of ICT for teaching and learning purposes (e.g., "I find ICT useful for my work as a teacher") – a construct that is an integral part of ICT attitudes (Scherer et al., 2015) and that is highly predictive of technology adoption (e.g., Teo, 2009). The "perceived ease of ICT use" (EASE) scale contained three items measuring general perceptions of how easy it appears to pre-service teachers to work with ICT, independent of the educational context (e.g., "It is easy to become skilled in the use of ICT"). Perceived ease of use also qualifies as a critical predictor of technology adoption (Teo, 2011). All scales were based on a six-point Likert scale ranging from 0 (*strongly disagree*) to 5 (*strongly agree*). The full set of items is presented in the Supplementary Material S2.

Data Analysis

Model estimation and evaluation. All constructs used to assess the TPACK-attitudes relations were represented as latent (unobserved) variables that are indicated by manifest (observed) indicators (Kline, 2016). Although manifest indicators of latent variables showed only marginal departures from normality, measurement and structural models were estimated with the help of robust maximum likelihood (MLR) estimation with standard errors and tests of fit that were robust against possible non-normality of observations and the use of categorical variables in the presence of at least four response categories (Rhemtulla, Brosseau-Liard, & Savalei, 2012). To evaluate the fit of the structural equation models specified to examine the TPACK-attitudes relations, we referred to common guidelines for an acceptable model fit (i.e., CFI ≥ .95, RMSEA ≤ .08, and SRMR ≤ .10; Hu & Bentler, 1999; Marsh, Hau, & Grayson, 2005). Nevertheless, these guidelines do not represent "golden rules" (Marsh, Hau, & Wen, 2004) – in fact, they do not fully apply to complex factor structures, such as second-order or nested-factor models (e.g., Khojasteh & Lo, 2015). All models were estimated in the software M*plus* 7.3 (Muthén & Muthén, 1998-2015).

Item parceling and scale reliability. Given the number of items (TPACK: 21 items, Attitudes: 11 items), the number of response categories (TPACK: 5 options; Attitudes: 6 options), and the number of factors or subscales (TPACK: 4 factors; Attitudes: 3 factors), the sample of $N = 688$ pre-service teachers is relatively small to obtain robust parameter estimates and standard errors. A structural equation model that treats item responses categorically and links TPACK and attitudes toward ICT contains about 200 parameters that need to be estimated – the resultant sample size-to-model parameter ratio is about 3.4:1. If item responses were treated continuously, the ratio would correspond to about 7:1 – a value that is at the edge of what researchers recommend for model estimation (Lei & Wu, 2012; Wolf, Harrington, Clark, & Miller, 2013). We consequently decided to reduce the number of model parameters to achieve optimal power for detecting effects, but, at the same time, ensure that this reduction does not affect the structural parameters of the TPACK-attitudes relations. A promising approach to this is referred to as item parceling. Item parceling represents a procedure that combines item responses in parcels by estimating their means or sum scores. If the factor structure of a scale or a group of items is known, and information on item factor loadings is available, items can be grouped together based on their factor loadings (Little, Cunningham, Shahar, & Widaman, 2002; Little, Rhemtulla, Gibson, & Schoemann, 2013). The results of an item parceling strategy are parcels which can be used as continuous indicators of latent variables. This procedure can produce models with better fit and less biased structural parameters than item-based models, particularly if scales are unidimensional

(Bandalos, 2002; Nasser-Abu Alhija & Wisenbaker, 2006; Sass & Smith, 2006). Yet, it is critical that the factor structure of a scale is known to create meaningful parcels (Little, Rhemtulla, Gibson, & Schoemann, 2013). For each scale, we created three item parcels.

Scale reliabilities were estimated as Cronbach's α and McDonald's ω_t. The latter is based on more relaxed assumptions on the measurement model of scales and might therefore provide a more accurate reliability coefficient than Cronbach's α (Revelle & Zinbarg, 2008). Nevertheless, Cronbach's α has been used widely for decades; to ensure comparability with other studies, Cronbach's α is reported next to ω_t.

Handling missing data and the clustered sample structure. The missing data that occurred in the present study (less than 4%) were handled by full information maximum likelihood estimation under the assumption that they occurred randomly (Enders, 2010). We further accounted for the clustered data structure (i.e., pre-service teachers clustered in teacher-training institutions) by adjusting χ^2 statistics and the standard errors of all model parameters with the TYPE = COMPLEX option in M*plus* 7.3 (Muthén & Muthén, 1998-2015). This adjustment results in Satorra-Bentler corrected χ^2 statistics, which form the basis for further model comparisons (Satorra & Bentler, 2010).

Results

Descriptive Statistics and Scale Reliabilities

As a first step towards establishing models that describe the relation between TPACK and ICT attitudes, we examined the descriptive statistics, characteristics of distributions, and reliabilities for each TPACK and attitude scale. This step is of importance as it facilitates the choice of an appropriate estimation procedure in subsequent structural equation models. Table 1 shows the resultant statistics. Pre-service teachers exhibited positive attitudes toward technology across all three core dimensions (i.e., general ICT attitudes, educational ICT attitudes, and ease of use), as indicated by high scale means approaching the average maximum of the response options. Concerning TPACK, pre-service teachers exhibited mediocre to high self-beliefs–there was yet no evidence for ceiling effects that would have uncovered overclaiming. The scale distributions were not severely skewed (Gravetter & Wallnau, 2017); a graphical inspection of their distributions confirmed that only marginal departures from normality existed. The descriptive item statistics confirmed these observations and exhibited only slightly skewed distributions (see Supplementary Material S3). Given that both item and scale distributions were not severely skewed, and ceiling effects could not be identified, models that assume normally distributed latent variables with item responses or parcels as indicators could be specified. At the same time, minor deviations from normality warrant the application of robust estimation procedures (e.g., MLR). All scales showed acceptable to high scale reliabilities.

Measurement Models and Item Parceling

In a second step, we established measurement models for the TPACK self-efficacy beliefs and the attitude scales. This step forms the prerequisite for describing the TPACK-attitudes relations in latent variable models. As described earlier, we performed item parceling—a procedure that groups items based on the information about their psychometric properties and conceptual framing. This procedure follows two steps: (1) Investigating the item parameters in measurement models; (2) Parceling items based on the outcomes of (1) and the conceptual assumptions on the factor structure of the entire scale or selected groups of items (Little et al., 2013). In the following, we describe the procedure of item parceling for both the TPACK and the attitudes toward ICT scales. Table 2 gives an overview of the resultant item parcels.

TPACK measurement model. In a preliminary study that was based on the same sample of pre-service teachers (Authors, 2017a), the investigation of the TPACK factor structure revealed that a nested-factor model represented the data best. This model assumed a general TPACK factor (gTPACK) and a specific factor representing technological knowledge (TK). The observation that TK stands out was also indicated by the slightly lower correlations to the other T-dimensions (Table 3). These findings were based on item-level analyses and targeted the invariance of the TPACK measurement model across gender.

In the present study, however, the TPACK measurement model is linked to a measurement model describing attitudes toward ICT, thus extending both the focus of the study and the complexity of the model. We consequently revisited the factor structure of TPACK using item parcels and created six parcels on the basis of conceptual and empirical considerations: First, item measuring TPCK, TCK, and TPK were grouped into three parcels because they conceptually belong to a single T-dimension. Moreover, the homogeneity of factor loadings of all TPCK, TCK, and TPK items ($Mdn[\lambda] = .76$, $\lambda = .55$-$.79$) supported this decision. The seven TK items were parceled based on their factor loadings and possible residual correlations among items. The resultant three parcels (see Table 2) exhibited high factor loadings, Parcel 1 ($\lambda = .83$), Parcel 2 ($\lambda = .89$), Parcel 3 ($\lambda = .82$).

Combining the six parcels (i.e., TPCK, TCK, TPK, and three TK parcels) into the nested-factor model Authors (2017a) have already identified at the item-level resulted in a well-fitting TPACK measurement model, SB-$\chi^2(6) = 21.4$, $p = .002$, SCF = 1.0567, RMSEA = .062, 90% CI RMSEA = [.035, .092], CFI = .995, TLI = .988, SRMR = .011. Figure 2 presents its model parameters. Both the general TPACK and the specific TK factors showed significant factor loadings so that these factors could be identified statistically. The nested-factor model served therefore as a representation of TPACK in all subsequent models. The specific TK factor represents the deviation of the three TK parcels from what is measured by TPCK, TCK, and TPK.

Attitudes measurement model. Unlike TPACK, evidence on the factor structure of attitudes toward ICT were not available. However, we hypothesized that the three core dimensions (i.e., general attitudes, educational attitudes, and perceived ease of ICT use) could be distinguished. Prior to testing this hypothesis, we examined the general attitudes toward ICT scale and established a single-factor model with five manifest item indicators. Factor loadings (*Mdn*[λ] = .75, λ = .53-.85) and modification indices suggested that items GATT1 and GATT2, as well as GATT3 and GATT4 could be parceled, leaving GATT5 as a standalone item. Hence, general attitudes were indicated by these three parcels in subsequent models (Table 2).

To test whether three, empirically distinct attitude factors existed, we first specified a correlated-traits model (Figure 3a). This model assumed three correlated factors and showed a reasonable fit to the data, SB-$\chi^2(24) = 143.2$, $p < .001$, SCF = 1.2017, RMSEA = .085, 90% CI RMSEA = [.072, .099], CFI = .953, TLI = .930, SRMR = .040. Inspecting modification indices, however, suggested the inclusion of a residual correlation between items EDATT1 and EDATT2. The modified model showed an acceptable model fit (SB-$\chi^2[23] = 118.0$, $p < .001$, SCF = 1.2103, RMSEA = .077, 90% CI RMSEA = [.064, .092], CFI = .963, TLI = .942, SRMR = .039); in comparison to the original model, model fit had significantly improved after including the residual correlation, SB-$\Delta\chi^2(1) = 29.2$, $p < .001$. The correlated-traits model indicated mediocre to high correlations among the attitude factors, ρ = .56-.78 (Figure 3a). These correlations might cause severe bias in structural parameters describing the TPACK-attitudes relations – caused by multicollinearity (Marsh, Dowson, et al., 2004). Whereas the correlated-traits model might indeed create multicollinearity issues, alternative factor models, such as second-order or nested-factor models might not. We therefore specified these alternative measurement models in subsequent steps.

The second-order factor assumes a hierarchical factor that captures the variance that is common to the three ICT attitudes (see Figure 3b). For the present data, this model had the same fit as the correlated-traits model and uncovered a non-significant residual variance of the general attitudes factor, $\zeta = 0.034$ ($SE = 0.056$, $p = .543$). The latter indicates that the three attitude factors are not clearly distinct (Gignac & Kretzschmar, 2017).

The pure form of the nested-factor model is often referred to as the "bifactor model" (Gustafsson, 1984; Holzinger & Swineford, 1937). Unlike the second-order factor model, this model assumes that a general factor underlies all item responses, interpreting the specific factors as residuals that capture variance over and above what is common to all items. For the present data, the bifactor model did not converge, primarily because at least one of the attitude factors could not be identified after controlling for overall attitudes. This observation is indeed common to bifactor models (Eid, Geiser, Koch, & Heene, 2016). We consequently dropped one of the specific attitude factors, attitudes toward the educational use of ICT (EDATT), resulting in a nested-factor model as it is shown in Figure 3c. This model exhibited good model fit (SB-χ^2[19] = 60.6, $p < .001$, SCF = 1.1714, RMSEA = .056, 90% CI RMSEA = [.041, .073], CFI = .984, TLI = .969, SRMR = .027) and showed significant factor loadings for all factors. The remaining correlation between the specific EASE and GATT factors was mediocre, $\rho = .51$. Although this model fitted the data very well, its interpretation is more complex than for the other models. Specifically, the general factor represents pre-service teachers' attitudes toward the educational use of ICT (reference factor), whereas the specific GATT and EASE factors represent what the GATT and EASE items measure over and above the educational attitudes. In this sense, the specific factors can be interpreted as deviations from the reference factor.

In sum, attitudes toward ICT could be described by three measurement models: (a) correlated-traits model; (b) second-order factor model; (c) nested-factor model. These three models shed light on the structure of attitudes from different perspectives and might be differentially useful for examining the TPACK-attitude relations.

Structural Equation Models

Based on the extensive analyses of the TPACK and attitudes measurement models and an initial inspection of factor correlations (see Table 3), four structural equation models may describe the TPACK-attitudes relations. We kindly refer the reader to Supplementary Material S4 for details on the corresponding M*plus* codes.

Model M1: Correlated-traits model. Linking the correlated-traits model of ICT attitudes and the nested-factor model of TPACK resulted in a model that fitted the data reasonably well (see Table 4 M1). Six structural parameters described the TPACK-attitudes relations (see Figure 4): General attitudes toward ICT were positively associated with gTPACK ($\beta = .25$, $p < .01$) and specific TK ($\beta = .61$, $p < .01$); the same held for perceived ease of ICT use (gTPACK: $\beta = .28$, $p < .01$; TK: $\beta = .45$, $p < .01$). For both attitude factors, the Wald test revealed that the associations with TK were significantly stronger than those with gTPACK (GATT: $\chi^2(1) = 8.9$, $p = .003$; EASE: $\chi^2(1) = 4.9$, $p = .027$).

Although educational attitudes were also positively related to gTPACK ($\beta = .15$, $p < .05$), they exhibited a negative relation to the specific TK factor ($\beta = -.45$, $p < .01$). The latter implies that more positive attitudes toward the educational use of ICT pre-service teachers have, the less competent they perceive themselves concerning the technological issues associated with the use of ICT, or vice versa. This finding, however, might be due to the high correlations among the attitude scales which cause multicollinearity issues and thus bias in parameter estimates and their standard errors (Marsh, Dowson, et al., 2004). Despite the result that the variance inflation factors for the three predictors were within the suggested boundaries (VIF = 1.9-2.8 < 4; O'Brien, 2007), TPACK-attitudes relations in the correlated-traits models can still be flawed. We therefore specified alternative models that may reduce the correlations among the attitude factors and thus the consequences of multicollinearity.

Model M1B: Correlated-traits model with equality constraints. One possible approach to handling multicollinearity is to constrain the regression coefficients for each outcome variable to equality (Marsh, Dowson, et al., 2004). For the data in this study, the model with equality constraints fitted the data well (see Table 4 M1B), yet worse than Model M1 (SB-$\Delta\chi^2[4] = 67.9$, $p < .001$), and showed positive and significant associations between all attitude factors and gTPACK ($\beta = .23$, $p < .01$) and TK ($\beta = .22$, $p < .01$). Factor correlations were still high, $\rho = .57\text{-}.79$.

Model M2: Second-order factor model. Combining the second-order factor model for ICT attitudes with the TPACK model resulted in a well-fitting model (see Table 4 M2 for model fit; see Figure 5 for model parameters). This model showed significantly positive relations between overall ICT attitudes and gTPACK ($\beta = .63$, $p < .01$), as well as overall ICT attitudes and TK ($\beta = .64$, $p < .01$). Considering this, more positive, overall ICT attitudes are associated with stronger self-beliefs in TPACK, and vice versa. The difference between these two relations was non-significant, Wald-$\chi^2(1) = 0.1$, $p = .936$.

Model M3: Nested-factor model. Finally, we combined the nested-factor attitudes model with the TPACK model (see Table 4 M3 for model fit; see Figure 6 for model parameters). In this model, overall ICT attitudes (gATT) were positively and significantly related to gTPACK ($\beta = .49$, $p < .01$) and TK ($\beta = .30$, $p < .01$); so were GATT (gTPACK: $\beta = .19$, $p < .01$; TK: $\beta = .35$, $p < .01$) and EASE (gTPACK: $\beta = .22$, $p < .01$; TK: $\beta = .36$, $p < .01$). For overall ICT attitudes, the regression coefficients did not differ significantly (Wald-$\chi^2[1] = 2.6$, $p = .107$); the same results held for the specific GATT factor (Wald-$\chi^2[1] = 3.1$, $p = .079$). The relation between EASE and TK was, however, significantly stronger than that between EASE and gTPACK, Wald-$\chi^2[1] = 4.4$, $p = .035$. These findings suggest that overall positive ICT attitudes (gATT) are linked to higher TPACK self-beliefs, independent of whether they represent educationally relevant TPACK aspects or mere technical dimensions of ICT use (TK). The gATT factor in this model represents the reference attitude, that is, educational attitudes. Although its relation to gTPACK – the more educationally relevant aspect of TPACK – was not significantly stronger, the observed tendency points to the link between TPACK and attitudes via educational relevance. Furthermore, we observed a tendency towards stronger relations of the specific GATT and EASE factors to the more technical TPACK aspect (TK).

Robustness checks. To test whether the above-mentioned TPACK-attitude relations were biased due to using item parcels instead of item raw responses, we checked the robustness of the findings by re-running Models M1-M3 (including M1B) with item-level data. Supplementary Materials S5 and S6 show the resultant models fit indices and structural parameters. Overall, the findings at the item-level agreed with those at the parcel-level, supporting their robustness.

Discussion

Substantive Perspectives on the TPACK-Attitudes Relations

The present study examined the relations between TPACK and attitudes toward ICT for a sample of pre-service teachers. A series of structural equation modeling approaches suggested that more positive attitudes toward ICT are associated with higher self-efficacy in TPACK, and vice versa. The different modeling approaches suggested that educational aspects of both TPACK and attitudes are linked on the one hand, and general aspects on the other hand. Generally, ICT attitudes as well as TPACK dimensions showed high within-construct correlations, thus challenging the interpretation of TPACK-attitudes correlations due to methodological issues such as multicollinearity (Marsh, Dowson, et al., 2004). Overall, second-order and nested-factor models circumvented these issues and facilitated the substantive interpretation of the relations.

From a substantive perspective, the positive relation between TPACK self-efficacy beliefs and attitudes toward ICT emphasizes the importance of how pre-service teachers perceive ICT, its ease of use, and usefulness for teaching and learning purposes, for their self-perceptions (Aubusson, Burke, Schuck, Kearney, & Frischknecht, 2014; Voogt et al., 2013). This relation links two distinct, yet related belief systems: that of beliefs about technology and that of beliefs about one's own competences for using technology (Ertmer, Ottenbreit-Leftwich, & Tondeur, 2015). Conducting secondary data analysis of the International Computer and Information Literacy Study (ICILS) 2013, Scherer et al. (2015) supported this finding by showing that different facets of teachers' perceived usefulness of ICT and their self-efficacy in teaching with computers are positively related. The two beliefs systems are therefore closely connected. This connection might be due to the conceptualization of constructs and measures: both attitudes and TPACK self-efficacy beliefs represent motivational constructs that are measured by self-reports (Nagengast & Marsh, 2014; Schunk, 1991; Zimmerman, 2000). This interpretation, however, requires further attention in experimental study designs which systematically manipulate the types of measures for both constructs.

Another important point to highlight for the interpretation of the findings is the issue of causality. Although the research model specified TPACK as the outcome and attitudes toward technology as predictors, it might well be that the relations between the two concepts are bi-directional. For instance, pre-service teachers' self-efficacy beliefs – that is, the beliefs about their capabilities within the TPACK knowledge domains – might well be a source of their attitudes toward ICT: Whenever pre-service teachers fail to master technology-related tasks, their TPACK self-efficacy beliefs could decrease and thus create negative attitudes toward technology (Tschannen-Moran & Johnson, 2011; Usluel, 2007). Indeed, in a study of 727 Chinese pre-service teachers, Sang, Valcke, Braak, and Tondeur (2010) integrated the two perspectives on the direction of TPACK-attitudes relations: The authors assumed that teaching self-efficacy predicted both educational ICT attitudes and computer self-efficacy; attitudes further predicted computer self-efficacy. In their model, attitudes toward the educational use of ICT served as outcomes *and* predictors at the same time. Overall, the causality represented in the TPACK-attitudes relations remains unclear.

Next to the overall positive TPACK-attitudes relations, the present study uncovered differences in the strengths of relations. Specifically, more educational attitudes were related to the pedagogical and content-related TPACK dimension (gTPACK), whereas technological attitudes showed stronger relations to TK. These observations point to the domain specificity of both attitudes and self-efficacy measures (Sang et al., 2010; van Braak, Tondeur, & Valcke, 2004; Zhang & Aikman, 2007), and further provide some evidence for the validity of the scores obtained from these measures. The latter confirms the conceptual distinction between educationally and technologically oriented dimensions of TPACK and attitudes toward technology. Along these lines, Scherer and Siddiq (2015) showed a similar result for teachers' self-efficacy in the context of teaching and learning with digital technology, and the delineation between an educational and technological TPACK-attitudes link supports Zhang et al.'s (2008) dichotomous conceptualization of attitudes. This distinction may have practical implications for teacher education and professional development in that teacher educators should pay attention to fostering student teachers' attitudes and self-efficacy beliefs toward both the educational and the technological aspects associated with use of ICT for teaching and learning. In fact, negative perceptions of the usefulness of technology and its ease might create barriers for their integration into teaching and learning (Scherer et al., 2015; Teo et al., 2008). In this regard, we encourage researchers to study the interactions between attitudes and TPACK in the context of technology acceptance (Hsu, Liang, Chai, & Tsai, 2013; Teo et al., 2016).

Overall, the positive relations between TPACK and attitudes identified in the current study highlight the importance of attitudes for developing critical competences and self-beliefs needed whilst using ICT for educational purposes. Teacher educators might therefore present pre-service teachers with opportunities that (a) showcase the usefulness and ease of ICT use for educational purposes, for instance, via worked examples; and (b) allow them to gain mastery experiences—critical sources of teacher self-beliefs (Tschannen-Moran & Hoy, 2007)—in using technology. Although the repertoire of achieving this is broad, instructional approaches in teacher education should consider the development of attitudes toward ICT and TPACK self-beliefs important.

Methodological Perspectives on the TPACK-Attitudes Relations

One of the main goals of the present study was to showcase how researchers in the field of educational technology could handle an important methodological issue: the occurrence of high correlations among predictor variables causing multicollinearity. This is in fact a critical issue because ignoring it can result in misleading and uninterpretable findings (Marsh, Dowson, et al., 2004). Besides this mere methodological perspective, there is a substantive perspective on it: many motivational constructs, or more precisely the scores obtained from their measures, are substantially correlated (e.g., Author, 2013; Bong, 2001; Nagengast & Marsh, 2014; Scherer & Siddiq, 2015). These high correlations challenge their conceptual distinction and point to the need for adequate approaches to handle them (Gignac & Kretzschmar, 2017). The present study proposed three core approaches under the framework of structural equation modeling and shed light on their strengths and limitations. The starting point for this demonstration was the observation that (a) pre-service teachers' attitudes toward ICT were highly correlated and hardly distinguishable empirically; (b) seemingly ambiguous TPACK-attitudes relations (e.g., negative relation between the attitudes toward the educational use of ICT and TK) occurred in a commonly used model that represented attitudes as correlated traits ("Correlated-traits model"). This observation challenges the adequacy of the correlated-traits model as a common modeling approach (Marsh, Dowson, et al., 2004). Nevertheless, the major strength of this model lies in its straightforward specification and interpretation of relations and factors. Overall, a careful review of the parameters derived from such a model or alternative models is needed.

Marsh, Dowson, et al. (2004) suggested constraining the structural parameters in the correlated-traits model. This approach can reduce the correlations among predictors and therefore lead to more interpretable results. At the same time, imposing equality constraints represents a strong conceptual assumption, that is, the equality of relations between independent variables and a dependent variable. Unlike Marsh, Dowson, et al. (2004), we do not recommend using this approach to handle possible effects of multicollinearity, because the equality assumption is conceptually often not justified. Moreover, equality constraints might not necessarily result in reduced factor correlations—in fact, in this study, factor correlations were still high, ρ = .57-.79. Alternative approaches, such as second-order and nested-factor modeling, might be more useful in this regard.

The second-order factor model establishes a general, overall factor that is based on three, first-order attitude factors. This approach is particularly useful if the relation between TPACK and *overall* ICT attitudes are in the major interest of the researcher. The high correlations among attitude scales are summarized within the overall factor. This approach, however, camouflages possible, differential relations between TPACK and attitudes across the different attitude dimensions – it simply provided relations between overall attitudes, gTPACK, and TK. Second-order factor models are furthermore useful to examine the differentiation of attitudes over time or describe the hierarchy of motivational constructs (e.g., Gustafsson & Balke, 1993; Marsh, 1987; Molenaar, Dolan, Wicherts, & van der Maas, 2010).

Nevertheless, their extensions to multi-group or more complex structural equation models often suffer from non-identification (Byrne & Stewart, 2006).

Finally, the nested-factor model was particularly useful for reducing multicollinearity, as it assumed an overall attitudes factor and two specific factors. The general attitudes factor differed from that specified in the second-order factor model, because it did not capture what is *common to all first-order factors* but what is *common to all items*. At the same time, the model distinguishes between different attitude factors and thus provides researchers with an opportunity to study differential relations to TPACK. Despite these advantages, nested-factor models are often hard to specify (given their complexity), and, more importantly, the factors need to be interpreted with caution. Specific factors represent what is measured by a set of items over and above a reference factors. In this study, educational attitudes (EDATT) served as the reference; hence, the perceived ease of ICT use factor represents the deviation of the EASE items from the EDATT items. Eid et al. (2016) explained how the interpretation of nested-factor models can be facilitated.

Overall, these three approaches present researchers with a toolbox to describe the TPACK-attitudes relations from different perspectives and circumvent possible methodological flaws due to the multicollinearity of different attitude dimensions. We recommend transferring these approaches to similar studies and research contexts. Nevertheless, researchers need to be aware of the models' strengths and limitations when interpreting the resultant parameters.

Limitations and Future Directions

The present study has some limitations worth noting: First, the pre-service teachers in this study were still enrolled in teacher education. Although information about their TPACK self-beliefs provides valuable insights into possible determinants of technology integration in classrooms, they may differ from those exhibited by in-service teachers who gather immediate mastery experiences with ICT in their classrooms (Teo, 2015). We consequently encourage further investigations focusing on comparisons of the TPACK-attitudes relations between pre- and in-service teachers. Second, this study focused on three core attitudes toward ICT. This selection was informed by the existing body of research on technology acceptance and integration which highlighted general attitudes toward ICT, perceived usefulness, and ease of ICT use as core attitudes (Scherer et al., 2015; Straub, 2009; Teo, 2009). Still, further attitudes or ICT-related beliefs might be considered in follow-up studies to broaden the view on the TPACK-attitudes relations. Moreover, the relevance psychological factors, such as pre- or in-service teachers' personality traits (e.g., openness and adaptability to novelty), demands further attention and should be considered as predictors of the TPACK competence development.

Conclusion

This study provided insights into the relations between TPACK dimensions and different types of attitudes toward ICT for a sample of pre-service teachers. The results indicated significantly positive relations suggesting that positive attitudes toward ICT are associated with higher self-beliefs in both the more educational TPACK dimensions (i.e., TPCK, TCK, and TPK) and the technological dimension (TK). From a substantive perspective, we conclude that educational and general attitudes matter for TPACK self-beliefs. As it is the designated goal of 21st century teacher education to stimulate the development of TPACK, we encourage teacher educators to consider the link between TPACK and attitudes, because it provides them with valuable information about what might block the development of TPACK. Nevertheless, the causality of the TPACK-attitudes relations needs to be further substantiated in experimental and longitudinal studies. From a methodological perspective, examining the TPACK-attitudes relations needs to account for the methodological issues caused by high correlations among several dimensions of attitudes toward ICT. To describe the TPACK-attitudes relations appropriately, a series of different models should be specified for researchers to take different perspectives on these relations. Overall, we argue that the link between TPACK and attitudes toward ICT is best examined by integrating substantive *and* methodological perspectives.

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Tables

Table 1

Descriptive statistics and scale properties

Scale	*M*	*SD*	*N*	*Mdn*	*Min*	*Max*	Skewness	Kurtosis	*SE*	α	ω_t
GATT	3.48	0.81	688	3.60	0.2	5.0	-0.39	0.23	0.03	.85	.91
EDATT	4.01	0.79	688	4.00	0.0	5.0	-1.04	1.93	0.03	.83	.90
EASE	3.37	0.94	688	3.33	0.0	5.0	-0.77	0.98	0.04	.89	.94
TPCK	2.65	0.63	665	2.80	0.0	4.0	-0.92	2.20	0.02	.86	.89
TCK	2.59	0.67	665	2.75	0.0	4.0	-0.72	1.31	0.03	.88	.90
TPK	2.68	0.60	665	2.80	0.0	4.0	-0.91	2.50	0.02	.90	.93
TK	2.51	0.72	665	2.57	0.0	4.0	-0.43	0.38	0.03	.91	.94

Note. GATT = General attitudes toward ICT, EDATT = Attitudes toward the educational use of ICT, EASE = Perceived ease of ICT use, TPK = Technological pedagogical knowledge, TCK = Technological content knowledge, TPCK = Technological pedagogical content knowledge, TK = Technological knowledge; α = Cronbach's Alpha, ω_t = McDonald's Omega-total (Revelle & Zinbarg, 2008).

Table 2

Overview of item parcels

Scale	*Parcel 1*	*Parcel 2*	*Parcel 3*
TPACK	TPCK1-TPCK5	TCK1-TCK4	TPK1-TPK5
TK	TK1, TK2	TK4, TK6	TK3, TK5, TK7
GATT	GATT1, GATT2	GATT3, GATT4	GATT5
EDATT	EDATT1	EDATT2	EDATT3
EASE	EASE1	EASE2	EASE3

Note. GATT = General attitudes toward ICT, EDATT = Attitudes toward the educational use of ICT, EASE = Perceived ease of ICT use, TPK = Technological pedagogical knowledge, TCK = Technological content knowledge, TPCK = Technological pedagogical content knowledge, TK = Technological knowledge.

Table 3

Factor correlations

	GATT	EDATT	EASE	TPK	TCK	TPCK	TK
GATT	1.00						
EDATT	.76	1.00					
EASE	.70	.56	1.00				
TPK	.57	.51	.54	1.00			
TCK	.56	.48	.57	.97	1.00		
TPCK	.53	.44	.50	.98	.97	1.00	
TK	.69	.44	.68	.82	.87	.81	1.00

Note. GATT = General attitudes toward ICT, EDATT = Attitudes toward the educational use of ICT, EASE = Perceived ease of ICT use, TPK = Technological pedagogical knowledge, TCK = Technological content knowledge, TPCK = Technological pedagogical content knowledge, TK = Technological knowledge. All correlations are statistically significant at the 0.1% level. Correlations between factors of the same underlying constructs are highlighted in grey. N = 688.

Table 4

Fit of the structural equation models describing the TPACK-attitudes relation

	Measurement models											
Model	TPACK	Attitudes	SB-χ^2	*df*	*p*	SCF	RMSEA	90% CI RMSEA	CFI	TLI	SRMR
M1	NFM	CTM	244.9	77	0.000	1.1409	.056	[.048, .064]	.973	.964	.035
M1B	NFM	CTM with equality constraints	315.2	81	0.000	1.1435	.065	[.057, .072]	.963	.952	.048
M2	NFM	SOFM	325.3	81	0.000	1.1554	.066	[.059, .074]	.961	.950	.046
M3	NFM	NFM	192.9	73	0.000	1.1350	.049	[.041, .057]	.981	.973	.029

Note. CTM = Correlated-traits model, SOFM = Second-order factor model, NFM = Nested-factor model; SB-χ^2 = Satorra-Bentler corrected χ^2 value (Satorra & Bentler, 2010), SCF = Scaling correction factor.

Figures

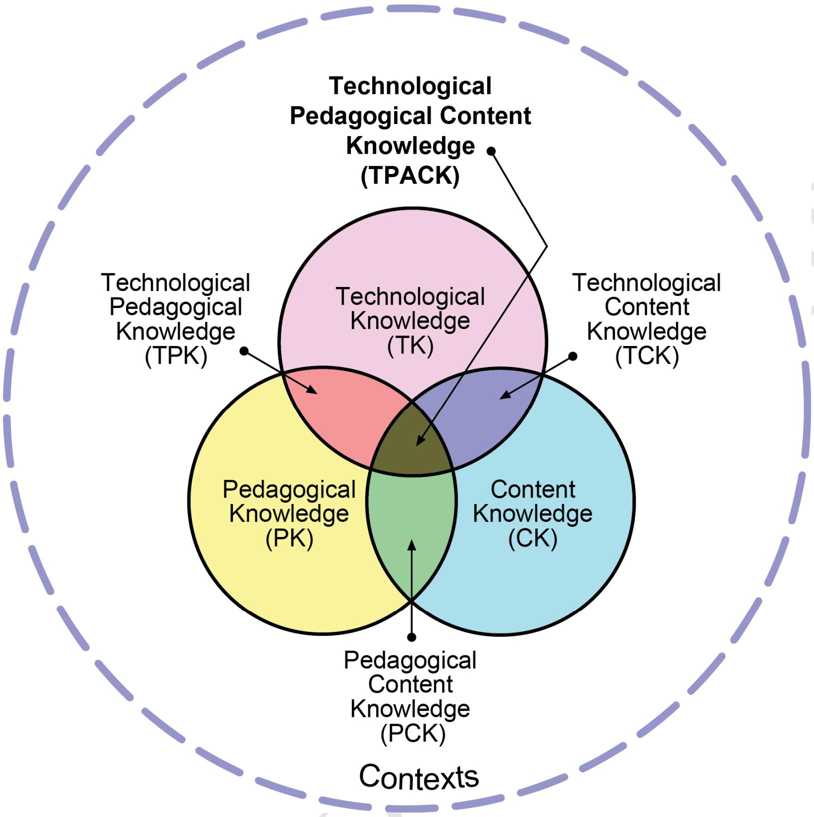

Figure 1. The TPACK model.

Note. Reproduced by permission of the publisher, © 2012 by tpack.org.

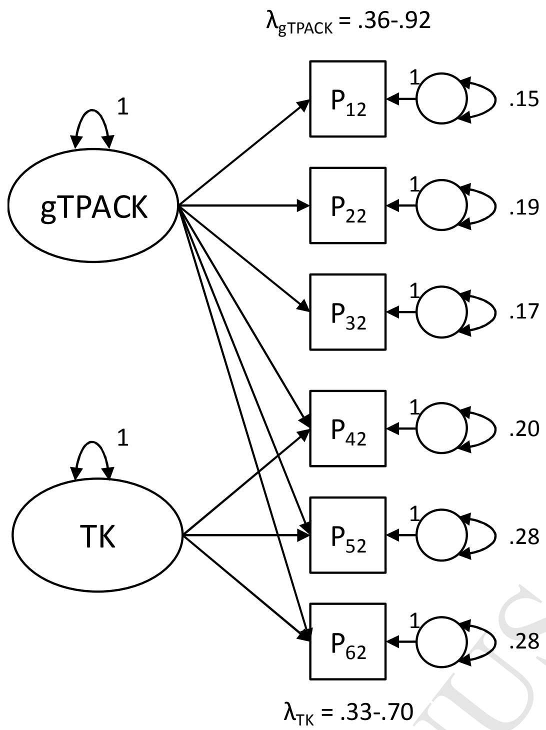

Figure 2. Measurement model describing the factor structure of TPACK.

Note. gTPACK = General TPACK factor, TK = Specific factor of technological knowledge (TK), P_{ij} = Item parcels. Factor loadings and residual variances are statistically significant (p < .01).

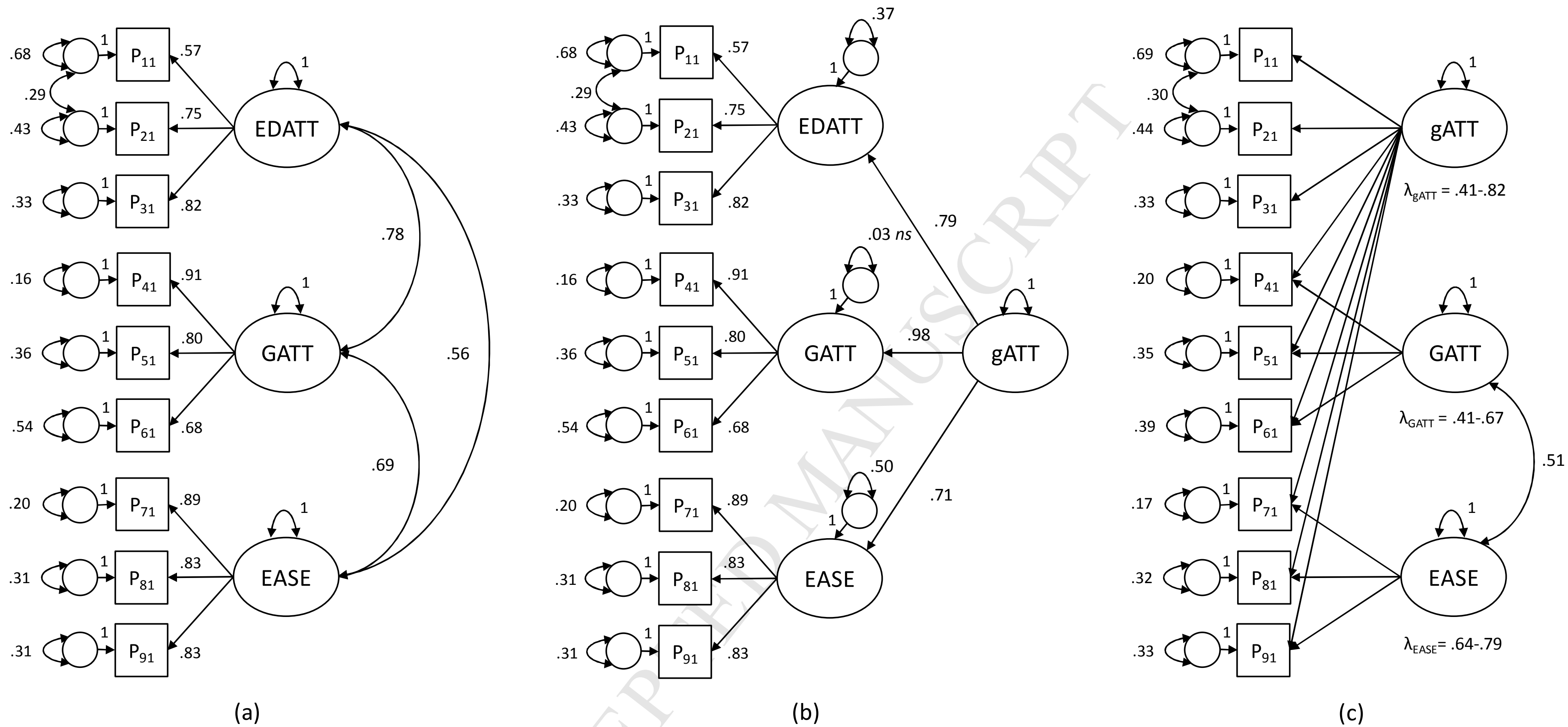

Figure 3. Measurement models describing the factor structure of ICT attitudes: (a) Correlated-traits model, (b) Second-order factor model, (c) Nested-factor model.

Note. GATT = General attitudes toward ICT, EDATT = Attitudes toward the educational use of ICT, EASE = Perceived ease of use, gATT = General factor of ICT attitudes, P_{ij} = Item parcels, *ns* = statistically not significant ($p > .05$). Factor loadings, residual variances, and factor correlations are statistically significant ($p < .01$).

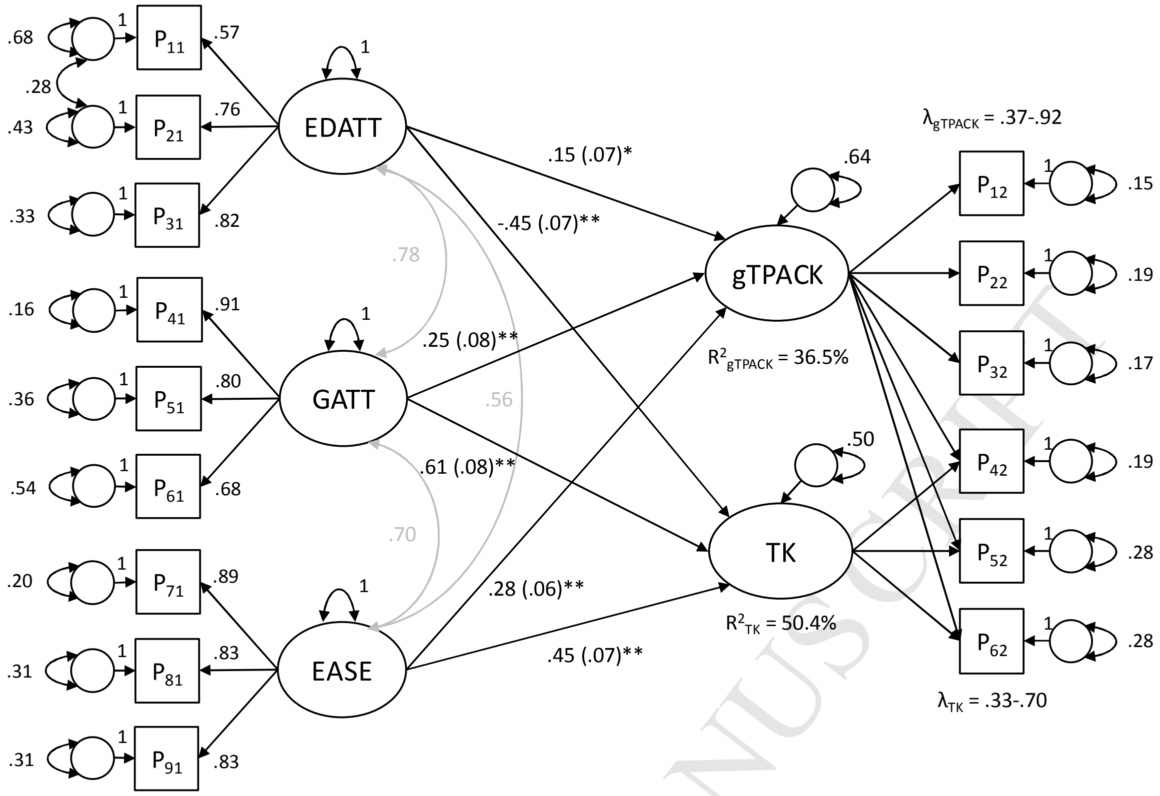

Figure 4. Structural equation model describing the relations between ICT attitudes and TPACK based on the correlated-traits model of attitudes.

Note. GATT = General attitudes toward ICT, EDATT = Attitudes toward the educational use of ICT, EASE = Perceived ease of ICT use, gTPACK = General TPACK factor, TK = Specific factor of technological knowledge (TK), P_{ij} = Item parcels. Factor loadings, residual variances, and factor correlations are statistically significant ($p < .01$). * $p < .05$, ** $p < .01$.

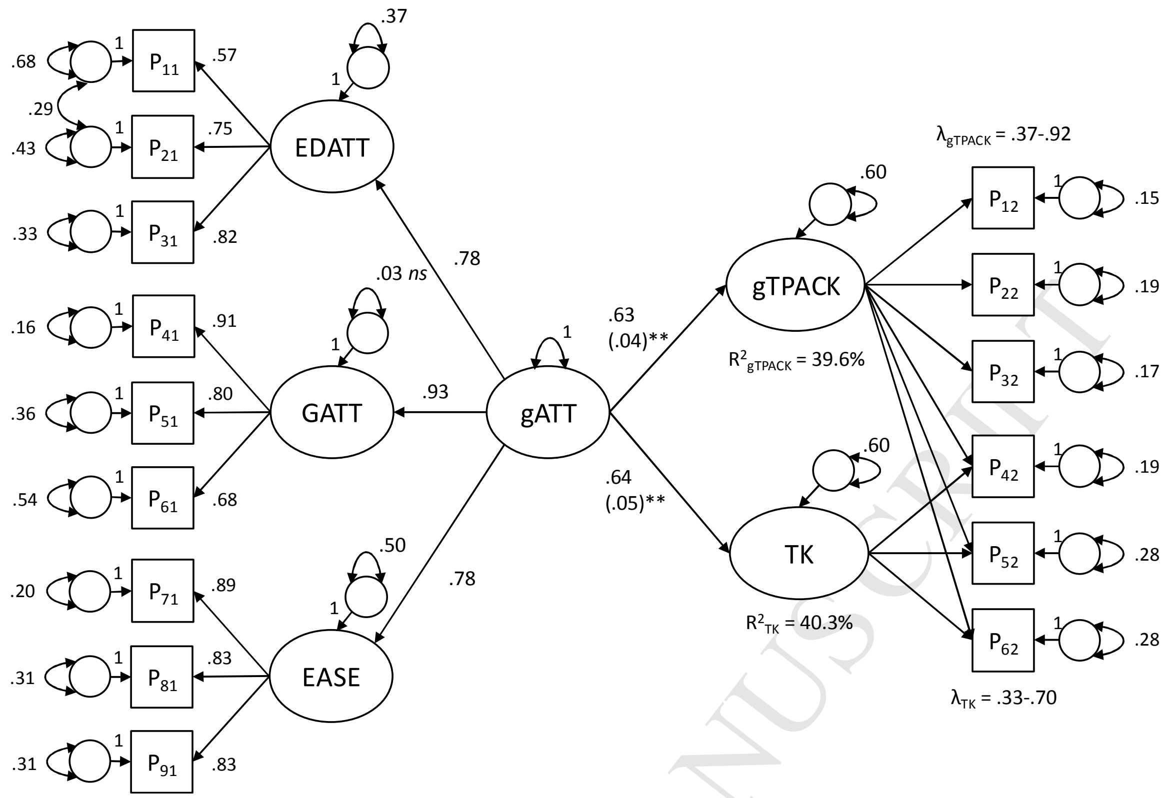

Figure 5. Structural equation model describing the relations between ICT attitudes and TPACK based on the second-order factor model of attitudes.

Note. GATT = General attitudes toward ICT, EDATT = Attitudes toward the educational use of ICT, EASE = Perceived ease of ICT use, gATT = General factor of ICT attitudes, gTPACK = General factor of TPACK, TK = Specific factor of technological knowledge (TK), P_{ij} = Item parcels. Factor loadings and residual variances are statistically significant ($p < .01$) if not marked by *ns* ($p > .05$). ** $p < .01$.

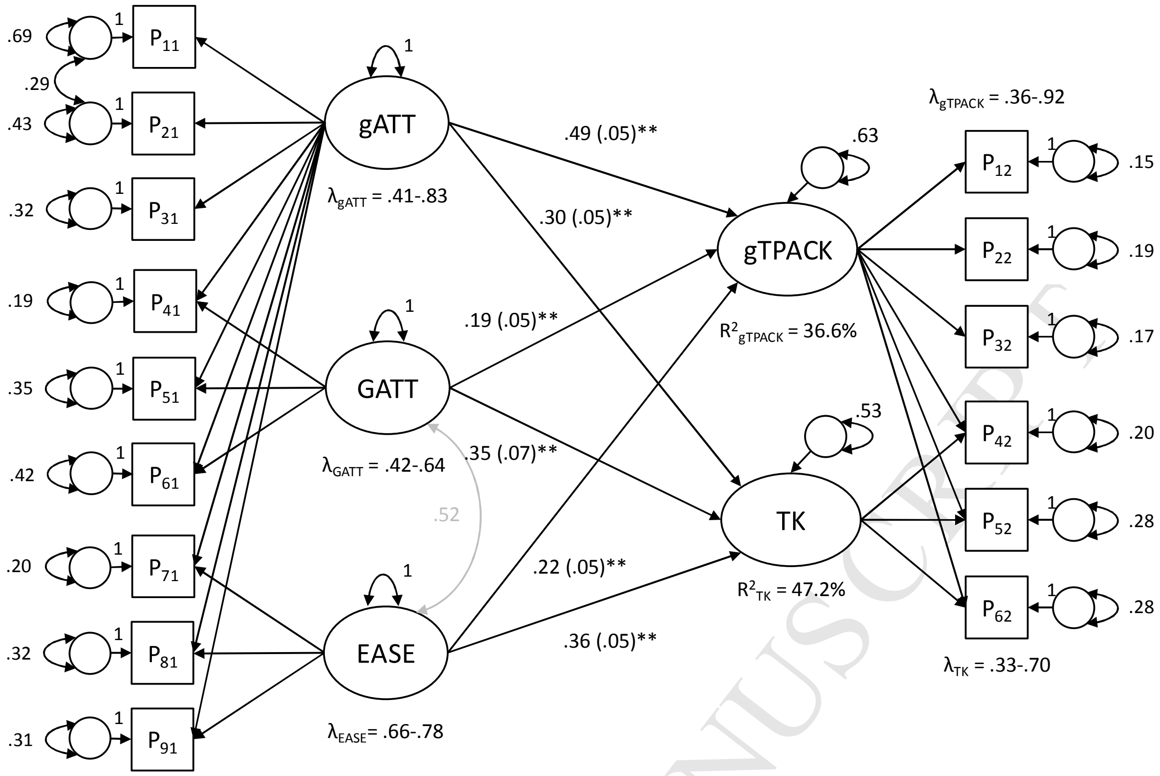

Figure 6. Structural equation model describing the relations between ICT attitudes and TPACK based on the nested-factor model of attitudes.

Note. GATT = General attitudes toward ICT, EASE = Perceived ease of ICT use, gATT = General factor of ICT attitudes, gTPACK = General TPACK factor, TK = Specific factor of technological knowledge (TK), P_{ij} = Item parcels. Factor loadings, residual variances, and factor correlations are statistically significant ($p < .01$). ** $p < .01$.

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Highlights

- The dimensions of pre-service teachers' ICT attitudes are highly correlated.
- A nested-factor model describes the structure of ICT attitudes best.
- ICT attitudes are positively related to general TPACK and specific TK.
- Educational and technological aspects of TPACK and attitudes are connected.
- Methodological considerations are needed to describe the TPACK-attitudes relations.