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Validity and Reliability of the Constructs of the TPACK Framework in the Context of Teachers of Quantitative Disciplines in Makerere University

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ABSTRACT

The Technological Pedagogical Content Knowledge (TPACK) framework operation alises the knowledge necessary for a teacher to use ICT in pedagogy as consisting of seven domains. The domains are content knowledge (CK), pedagogical knowledge (PK), technological knowledge (TK), pedagogical content knowledge (PCK), technological pedagogical knowledge (TPK), technological content knowledge (TCK), and technological pedagogical content knowledge (TPACK). Therefore, this study sought first, to establish the validity and reliability of each of the seven constructs. Second, to test whether the seven constructs were independent. Third, to re-examine whether the seven-factor TPACK model was reasonable. A sample of 87 was chosen from among 500 teachers of quantitative disciplines in Makerere University in Uganda who filled a self-administered questionnaire. The analysis involved using confirmatory factor analysis (CFA) and Cronbach alpha for the first objective; Pearson linear correlation (PLC) for the second objective; and exploratory factor analysis (EFA) for the third objective. (CFA) and Cronbach alpha for the first objective; Pearson linear correlation (PLC) for the second objective; and exploratory factor analysis (EFA) for the third objective. CFA and Cronbach alpha suggested that the seven constructs of TPACK were valid and reliable. However, PLC revealed that the seven constructs were highly inter-correlated. EFA revealed that while the TK and TCK constructs loaded together, the rest of the constructs (TPACK, PCK, CK, TPK, PK and PK in that order of importance) were distinct. It was recommended that researchers should continue using the TPACK framework as reasonable but at the same time while looking for avenues of refining it since it was found not to be perfect.

Introduction

There are seven knowledge domains from TPACK which combines the three components as: content, pedagogy, and knowledge (Aqip et.al, 2018). The seven knowledge domains are Content Knowledge (CK), Pedagogical Knowledge (PK), Technological Knowledge (TK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Technology, Pedagogy and Content Knowledge (TPACK). Aqip et al. defines CK as knowledge about learning materials that are to be taught and Koehler et al (2013 p.14) calls it the subject matter to be learned or taught which includes concepts, theories, ideas, organizational frameworks, evidence, proof, established practices and approaches toward developing such knowledge. Aqip et al. define PK as the knowledge of methods and processes in learning including knowledge about classroom management, assessment and lesson plans and TK as the knowledge of verity in technology, from low-tech to technology to digital technology. TK is related to fluency in technology and ability to apply it to work and everyday life, recognize when technology can enhance or hinder the achievement of a goal, and to continually adapt to technological changes (Koehler et al. 2013, p. 15). PCK is the knowledge of the learning process in line with the material to be taught, covering the core business of teaching, learning, curriculum, assessment, and reporting and the links among curriculum assessment, and pedagogy (Aqip et al. 2018, Koehler et al 2013). TCK is the knowledge of how technology can provide or constrain a new representation from a particular subject. Aqip et al conceptualize TPK as the knowledge about how various technologies can be used in the learning process and TPACK as knowledge needed to integrate technology in the learning process (p. 3).It is the basis of effective teaching with technology requiring an understanding of the representation of concepts using technologies, pedagogical techniques that use technologies in constructive ways to teach content knowledge Koehler 2013, p. 16). Having such a background, many researchers studied TPACK for different purposes and the following scholars aimed at testing TPACK's reliability and validity.

Omar et al. (2017) explored the teachers' use of information technologies having realized it as a dynamic intrinsic element to a teacher's pedagogic trade. They affirmed that studies on this issue had showed that sometimes technology was not efficiently used due to low levels of teachers' self-efficacy to use ICT in the classroom. Omar et al. reviewed the relationship between teachers' self-efficacy, cognitive style in the field dependence-independence (FI) dimension and TPACK as well as investigating the influence of Teachers' performance area on self-efficacy and TPACK. They defined self-efficacy as the perception / judgment that

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individuals have of their own abilities regarding the knowledge and skills related to the use of computers to achieve different objectives (Omar et al. 2017, p. 2 &3). In this view, teachers with better levels of self-efficacy in the use of ICT would probably integrate it in the development of different pedagogical activities in their respective subjects and vice versa.

To train teachers with low self-efficacy, Omar et al. says that Koehler and Mishra's TPACK framework can be used. Their research employed cognitive style as another variable that could be associated with use of ICT in pedagogy (UIP). According to Field dependent –independence dimension, subjects dominated by FI perform better than their field dependent (FD) classmates when using computational environments.

Omar et al (2017) used 208 teachers from 10 public school in Valle de Tenza, Boyaca in Colombia applying embedded figures test (EFT), self - efficacy and TPACK tests. By use of correlations and Variance (ANOVA) analyses, they registered significant associations between cognitive style, self-efficacy and TPACK. In addition, they substantiated significant differences in Self efficacy, Technological knowledge and TPACK according to the performance area and cognitive style. They used 'teacher computer efficacy scale' instrument registering Cronbach's a = 0.90. The TPACK questionnaire to determine pedagogical, technological and content knowledge developed by Jong and Fang had a reliability or Cronbach's a = 0.960. The cognitive style test using embedded figures test to determine FDI dimension was at an average of 23.42 and standard deviation of 10.313 (Omar et al. 2017, p. 5).

Conclusively, there were significant negative associations between teachers' age and computer self-efficacy, positive correlation between cognitive style and TK and significant differences between the teachers' performance area and self-efficacy especially between computer science and technology teachers and basic primary and social studies teachers. Lastly, their results on self-efficacy in basic primary teachers contradicted the findings of another study (Altun and Akyildiz, 2017) which reported high levels of self-efficacy toward ICT and technology integration by primary teachers (Omar et al. 2017, p.10).

Kartal et al (2016) in their study pointed out that the use of technology in teacher education was focused on learning the different technologies. But they observed that having technological knowledge is not enough for technology integration. Hence for successful technology integration, standards for teachers, students and administrators were developed by ISTE such that teachers can facilitate student learning and creativity, design digital age learning experiences and assessments; model digital age work and learning; promote and model digital citizenship and responsibility and engage in professional growth and leadership. Kartal et al believed that Self-reported scales were the most common measurement tools for TPACK and that Surveys could inform about participants' beliefs, views, attitudes, and dispositions which are the most effective on their decisions related to teaching with or without technology. However, they contended that most of the TPACK surveys lacked reliability and validity. In their study, a valid and reliable survey; TPACK Self-Assessment Scale (TPACK-SAS) was developed to identify pre-service teachers' self-perceptions and self assessments of their TPACK. The steps (item pool, expert review, item performance analyses, validity, reliability and factor analyses) suggested by DeVellis (2003) were followed in the scale development process. 119 items [CK (13), PK (24), TK (21), TCK (10), TPK (16), PCK (21), and TPACK (14)] constituted the item pool (negative items were not included in the TPACK-SAS) (p.11). The aim was to measure the TPACK framework suggested by Mishra and Koehler. Secondly, the study aimed at developing a valuable and reliable TPACK survey to measure pre-service teachers' perceptions about the use of technology in teaching. TPACK-SAS was administered to 754 pre-service teachers. After the analyses, the framework consisted of seven sub domains, similar with the original one, and 67 items. Pre-service teachers were also asked whether they have their own computers or not, where they access internet, amount of time they spend using computers, proficiency of using computers and their intentions to use computers. The relationships between these variables and TPACK sub domain were investigated. To avoid ambiguity found in earlier studies about the theoretical notions of TPACK, Kartal et al. reviewed a lot of literature (p.22).

Glowatz & O'Brien (2017) while revisiting academic engagement and technologies said that there was increased research into the use of innovative information and communications technology (ICT) for academic purposes. They observed that research explorations were about the opportunities presented by ICT and social media as innovative tools for teaching and improving student learning. Their study pointed out that the role of the academic in navigating the use of ICT in their teaching in Higher Education (HE) had been overlooked in discussions. In reference to Koehler and Mishra (2009) who proposed the technological, pedagogical and content knowledge (TPACK) framework to explore the relationship of technology in teaching and O'Brien and Glowatz (2013) who investigated the suitability and relevance of the TPACK framework in the context of academic engagement in Higher Education, Glowatz and O'Brien observed that the elements of the teaching dynamic were disregarded. Consequently, Glowatz and O'Brien's primary aim was to examine the School of Business' academic staff's understanding, perceptions and opinions on aspects of the use of educational technologies for electronic learning (e-learning). Their objectives were to explore what academic staff defined as e-learning, to examine how they use it to enhance teaching and to identify good practice for e learning implementation. They also evaluated the use of the TPACK framework in the exploration of technology in higher education by academics. Specifically, their study hinged on a key question 'How do academics currently make use of technology to teach at higher education?' This was on the basis that academics are at the forefront of electronic learning as they are the experts in providing content to the learning (student). Consequently, they believed that the academics' perceptions, attitudes and behaviours related to e-learning would be the single greatest determinant of success. They argued that majority of research around technology and learning had focused on the students' experience, as opposed to that of the academics. So they set out to investigate the educational technologies and to develop a model of technology for e - learning.

Glowatz and O'Brien's assertion that perceptions, attitudes and behaviours related to e- learning being the single greatest determinant of success in e-learning is overstated but e-learning needs to be combined with students' exposure, personal psychological beliefs and availability of IT tools in the teaching environment. Hence, research on familiarity with and availability of ICT tools and psychological and design beliefs of both academics and students is important.

Mishra and Koehler (2006) proposed a framework which predicts the teachers' Use of ICT in pedagogy (UIP). They conceptualized this framework as Technological Pedagogical Content Knowledge (TPACK). According to Mishra and Koehler, teachers need three domains of knowledge namely content knowledge (CK), pedagogical knowledge (PK) and technological knowledge (TK) for effective UIP. Having defined CK as the "knowledge about the actual subject matter that is to be taught" (p. 1026), Mishra and Koehler argued that a teacher's CK is very important because it influences how the teacher engages students with the subject matter and how the teacher evaluates and uses instructional materials like ICT. Mishra and Koehler went on to define PK as the "knowledge about the processes and practices or methods of teaching and learning and how it encompasses… overall educational purposes, values and aims" (p. 1026). They contended that PK gives a teacher an "understanding of how students construct knowledge, acquire skills, and develop habits of mind and positive dispositions toward learning" (p. 1027). Further still, having defined TK as a teacher's "knowledge about standard technologies, such as books, chalk and blackboard, and more advanced technologies, such as the Internet and digital video" (p. 1027), Mishra and Koehler argued that TK gives a teacher the ability to install, operate and use ICT tools in order to enhance teaching and learning.

The interaction between the three primary knowledge domains, CK, PK and TK gives rise to three secondary knowledge domains namely pedagogical content knowledge (PCK), technological content knowledge (TCK) and technological pedagogical knowledge (TPK). These combinations of knowledge, according to the TPACK framework, enhance UIP by teachers. Mishra and Koehler (2006) defined PCK as the "knowledge of pedagogy that is applicable to the teaching of specific content" (p. 1027). According to them, PCK helps the teachers in the representation and formulation of concepts and gives them the knowledge to discern what makes particular concepts difficult or easy to learn. Mishra and Koehler further defined TCK as the "knowledge about the manner in which technology and content are reciprocally related" (p.1028), arguing that TCK helps the teacher to know the manner in which the subject matter can be changed by the application of ICT tools. Mishra and Koehler defined TPK as the "knowledge of existence, components, and capabilities of various technologies as they are used in teaching and learning settings, and conversely, knowing how teaching might change as the result of using particular technologies" (p. 1028). To that effect, they indicated that TPK is important to teachers because it helps them to understand the range of ICT tools that exist for a particular task. As such the teacher is also able to choose ICT tools based on their fitness, have strategies for using the ICT tools' affordances, and know the pedagogical strategies which he/ she can apply for use of ICT.

When PCK, TCK and TPK knowledge domains interact, they form a triad, technological pedagogical content knowledge (TPACK), which according to TPACK, is the ideal combination of knowledge needed by a teacher to engage in UIP. The seminal article (Mishra & Koehler, 2006) defined TPACK as "an emergent form of knowledge that goes beyond all the three components (content, pedagogy, and technology)" (p. 1028). As such, they affirm that TPACK gives a teacher a chance to know what makes concepts difficult or easy to learn and how the use of ICT can help to scale down some of the difficulties that learners face while learning. TPACK also helps a teacher to develop pedagogical techniques that use ICT in constructive ways to teach content. In summary, TPACK suggests seven knowledge domains (CK, PK, TK, PCK, TPK, TCK, & TPACK) as major determinants of UIP by teachers as illustrated in Figure 1.

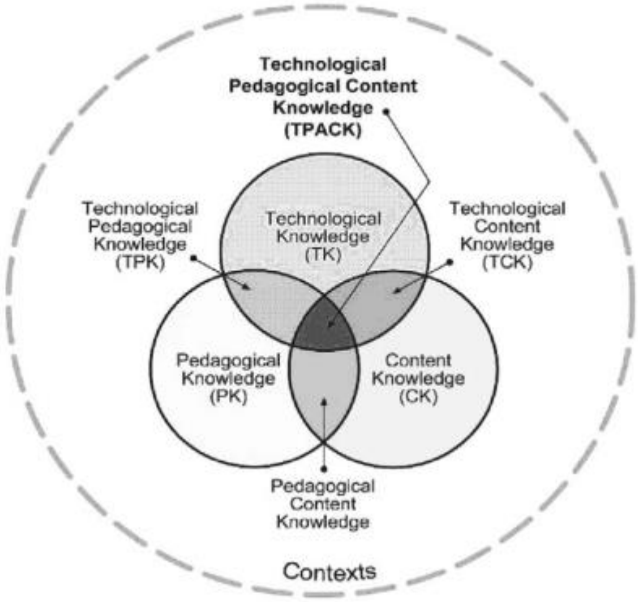

Figure 1. The TPACK framework for UIP.

Source: Mishra & Koehler (2006, p. 1025, Figure 4)

Several researchers have developed and tested instruments to measure TPACK among teachers and /or students. For example, Valtonen et al (2017) carried out an update of TPACK to measure pre-service teachers' 21st century skills, asserting that teachers must familiarise with various pedagogical approaches and appropriate ways of using ICT to develop their students' skills. They said that TPACK framework provides a theoretical model for studying ways in which teachers' use ICT in education. Valtonen et al asserted that TPACK framework faced difficulties especially on the instruments used for studying TPACK, that is, changes related to psychometric properties of instruments and areas of pedagogical knowledge. Consequently, they introduced a new TPACK 21 questionnaire which was grounded on 21st century skills. The TPACK 21 questionnaire was validated using confirmatory factor analysis (CFA). The results gave a six factor CFA model aligning with the TPACK theoretical framework. They also discussed the associations among the TPACK constructs and the weak and strong areas of pre-service teachers' TPACK.

Valtonen et.al contended that the 21st century skills were emphasised in different countries but in the actual teaching practice, the role of such skills was much weaker. That is, why they saw the need of developing a framework that was based on theory and empirical evidence to enable the measurement and follow-up of pre-service teachers' educational paths. The researchers aimed at combining this framework with TPACK, a well known theoretical approach among researchers studying (pre-service) teachers' use of ICT. Valtonen affirmed that TPACK was designed for 21st century skills (Mishra et. al, 2010) but there was need to design a TPACK measurement instrument aligning with 21st century skills. The 21st century skills place emphasis on pedagogy and pedagogical practices of collaborative learning and problem-solving (Valtonen 2017, p. 2).

Their study aim was to introduce a tested instrument for measuring pre-service teachers' TPACK grounded pedagogically on 21st century skills. They used an online self-assessment TPACK-21 instrument on novice pre-service teachers which was developed after reviewing the already available TPACK instruments by adding areas of 21st century skills. They then conducted two pilot tests with 86 items but later were reduced to 38 statements whose reliability level was above alpha 0.80 (Valtonen et al. 2017, p. 6). The CFA was intended to check how the measured TPACK constructs aligned with the theoretical TPACK framework and test the TPACK-21 instrument. The Cronbach's alphas for TPACK-21 were; for PK ($\alpha = .93$), CK ($\alpha = .92$), TK ($\alpha = .88$), PCK ($\alpha = .95$), TPK ($\alpha = .95$), TCK ($\alpha = .89$), TPACK ($\alpha = .96$) and all correlations significant $p < .05$ (p. 21, 23). However they say, "the actual TPACK factor did not fit the data (i.e. poor fit indices and multiple modification indices), and therefore it was left out of the final model. After removing the TPACK factor, the factor structure fit the data acceptably with six latent factors (CFI = 0.98, TLI = 0.98, RMSEA = 0.063 [0.057; 0.069])" (Valtonen 2017, p.21).

Conclusively, this study presented the TPACK framework and outlined the challenges related to TPACK available instruments. They also outlined ways of developing the current TPACK research instruments to better consider 21st century skills with empirical evidence.

Hasniza & Tengku (2016, p.2) carried out a case study on the validation of TPACK in a Malaysian secondary school context having realized that the government had equipped computer facilities in 8,000 schools and was to equip high speed 4G mobile internet to 10,000 Primary and secondary schools. Hasniza et.al believed that with ICT, learning could become interesting allowing learners, for example, to learn language using computer games in acquiring vocabulary and utilizing mobile learning for distance learners. Nevertheless, they contended that teachers' ability to use the provided tools was highly critical in realising the benefits of ICT and developing pre-service teachers' skills to incorporate ICT into their teaching effectively remained a concern for initial teacher education. Furthermore, they believed that effective integration of ICT in teaching and learning requires the teacher to understand how ICT weaves with pedagogy and content, better known as Technological Pedagogical Content Knowledge (p.3) Hence, their study focused on the validation of a Technological Pedagogical Content Knowledge (TPACK) instrument for using ICT in teaching and learning effectively in a Malaysian secondary school setting. Their sole objective was to confirm a seven factor TPACK model which includes Technological Knowledge, Content Knowledge, Pedagogical Knowledge, Pedagogical Content Knowledge, Technological Pedagogical Knowledge, Technological Content Knowledge and Technological Pedagogical Content Knowledge. All in all, their study sought to establish the reliability and validity of TPACK and to evaluate the goodness of the TPACK measurement model (p.8).

They adapted a TPACK survey by translating from the source language (SLQI) to the target language (Bahas Malaysia version) by three ICT bilingual people and then used a pretesting, decentering, back translation and committee approach to ensure appropriateness and accuracy. The Bahasa Malaysia version of the TPACK survey was piloted with 30 pre-service teachers to re-examine its internal consistency because of the adaptations and the different setting. Findings showed the reliability of the constructs that ranged from 0.86 for Pedagogical Content Knowledge (PCK) to 0.92 for Technological Content Knowledge (TCK). Then they administered the adapted TPACK survey to 150 pre-service teachers enrolled in a university. Confirmatory factor analysis (CFA) of the adapted TPACK survey was preceded by assessing the fit of the measurement model with the data in the study based on a priori theoretical model. It was observed that the indicators were strongly related to their purported latent factors (ranging from $\beta = 0.52$, $t = 5.46$ to $\beta = 0.85$, $t = 6.87$, significant at $p < 0.001$) establishing the convergent validity of the measurement model (p.13). The correlations between the seven knowledge domains were all positive, ranging from the lowest value $r=0.48$, $t=3.75$, $p < 0.001$ between TK and PK, to the highest, $r=0.94$, $t=5.50$, $p<0.001$ between TPK and TPACK and $r=0.94$, $t=5.97$, $p<0.001$ between PCK and TPACK (p. 14). The findings revealed that the measurement model adequately fit with the data collected within a Malaysian secondary school context, also lending validity to the adapted TPACK instrument used in this study. Significantly, the adapted and translated TPACK survey was found to be a valuable self-report instrument for measuring pre-service teachers' TPACK knowledge. However, a greater understanding of TPACK was required for pre-service teachers before adequate gains in using ICT in teaching would be achieved. Therefore, they recommended that this knowledge could be integrated in the Initial Teacher Education curriculum with more attention to improving access to ICT in Initial Teacher Education and the schools (p.1). There was no clear understanding and interpretation of the TPACK instrument since some questions looked similar to PSTs and yielded same responses from teachers, that is, technology still foreign to the older generations, learners rather than teachers knowing and using technology applications than teachers themselves, and also infrastructure still limited, and there is testing and training of some groups while others are left out such that the people are at different knowledge levels of TPACK.

Kirayi (2016) conducted a study on the development of a TPACK Self-efficacy Scale for pre-service Science Teachers using the theoretical framework of technological pedagogical and content knowledge (TPACK) suggested by Koehler and Mishra (2006). Kirayi said that all the TPACK studies in his literature referred to the concept of PCK as the starting point of TPACK. However, he notes that there is not a universal consensus on the scope of PCK and TPACK. That all researchers detail the concepts differently and the only point of consensus is the theoretical model advanced by Mishra and Koehler which is formed from the intersection of three different sets and has seven subheadings as technology knowledge (TK), pedagogy knowledge (PK), content knowledge (CK), technological pedagogical knowledge (TPK), technological content knowledge (TCK), pedagogical content knowledge (PCK), and technological pedagogical content knowledge (TPCK). He further observes that in the studies conducted after the emergence of this model, researchers have deepened and widened these seven steps considering their branches and backgrounds. Hence, his study's aim was to develop a TPACK self-efficacy scale for pre-service science teachers. The scale consisted of seven subscales; CK, TK, PK, TCK, TPK, PCK, and TPACK with a total of 55 items. 467 pre-service science teachers from four different universities in Turkey participated in the study. The subscales of this 55-item scale were determined and confirmed by using confirmatory factor analyses. The Cronbach's alpha reliability coefficient of the scale was calculated as 0.969. Following the modification suggestions, confirmatory factor analyses showed that the model fit the scale adequately. Kirayi observed significant differences between the bottom and top groups; that showed the sufficiency of the items' discriminatory powers. As the result of those analyses, it was found out that the scale had the necessary properties required for measuring the TPACK self-efficacy perceptions of pre-service science teachers. One of the strong sides of the scale is that it includes subscales that are consistent with the theoretical framework suggested by Kohler and Mishra (2006). The most distinctive feature of the scale was the Content Knowledge subscale since the scale developed in Kirayi's study was customised to particular science learning areas unlike other TPACK scales that measured content knowledge in general terms. His scale represented Physical Science, Chemistry, Biology, Earth Science, and Astronomy, as individual items, and this constitutes one of its strongest sides. Another strong side of the scale was that, items related to science process skills /skills of scientific inquiry and science-technology-society-environment, which are indispensable to science education, were included as a subscale in Kirayi's scale. Another remarkable feature of the scale is that common misconceptions in science were included in content knowledge. Besides the above, another important feature of the scale was that the items of the scale were written by grouping a wide range of technologies from traditional technologies to digital technologies and the internet under certain themes, e.g., digital software, social networks, science lab materials, basic software, mobile learning tools, etc. In the scales presented in the literature review, the names of these technologies were listed individually but in his study, names related to technology were given in parenthesis as examples to the main titles. This feature of the scale contributes to the prolongation of the lifetime of technology, which is the fastest changing subscale of TPACK scales. His scale only tackled the science areas in particularised way. What about other non-scientific disciplines? The study was done in Turkey, so elsewhere the scale can easily change.

Chai et.al (2018) conducted a study and proposed a new conceptualisation of technological pedagogical content knowledge (TPACK) that centres exclusively on the intersection of technology, pedagogy, and content for selected dimensions of 21st century learning. During their research, they discovered that the emergence of TPACK had not transformed the state of technology integration in the classrooms and more research on developing teachers' TPACK specifically to promote 21st century competencies through various pathways was needed. Furthermore, quantitative TPACK research had focused on validating the seven-factor model and applying the validated models in the assessment of teachers' efficacy growth before and after ICT courses (Chai et al. 2018, p. 2). Chai et al. also contend that while several studies had validated the seven-factor model quantitatively, recent research had challenged the model with deferent ways of considering TPACK. Owing to the above facts, Chai et al (2018) attempted to conceptualise a new representation of a specific TPACK for 21st century, which they labeled as TPACK-21st century quality learning (TPACK-21CQL). The TPACK-21CQL dealt directly with the intersection among technology, pedagogy and content of the seven-factor model of TPACK while ignoring the intermediate factors such as Technological pedagogical Knowledge (TPK), Pedagogical content knowledge (PCK) or technological pedagogical content knowledge (TCK) or the elementary factors like technological knowledge (TK), Pedagogical knowledge (PK) or Content knowledge (CK). Thus, instead of defining TPACK as comprising various sub factors, it added to the current TPACK research by exploring directly the intersection of TPACK, hypothesising that the central TPACK factor could be multidimensional when addressing the selected dimensions of 21st century learning (Chai et al 2018, p. 3). Given the new conceptualization of TPACK, the study aimed at generating and validating an instrument that represented TPACK-21CQL, investigating how the pre-service teachers' beliefs and TPACK-21QL efficacies change throughout an intervention program designed around TPACK-21QL, and lastly to examine the Structural Equation Model (SEM) of design beliefs and TPACK-21QL before and after the intervention to further understand the effects of the intervention.

Using 564 participants, teachers' design beliefs were investigated with the teachers' TPACK. Given the conceptualisation, a new instrument was designed and validated. Then an associated intervention program to enhance the pre-service teachers' TPACK was designed and the pre- and post-course surveys were conducted (Chai et.al, 2018 pp 1). To unpack the relationships between teachers' design beliefs and their TPACK, they constructed and validated structural equation models. Their findings indicated that the instrument possesses good construct, discriminant and convergence validity, and reliabilities. The intervention enhanced the teachers' TPACK efficacies and their design beliefs significantly and the structural equation models indicated that the teachers' design beliefs are significant predictors of the teachers' TPACK. In the findings exploratory factor analysis had eight factors with Eigen values above 1, the total variance explained was 73.0%. Nine factors with loadings below 0.5 were removed and the overall alpha of the remaining items was 0.94. The implications of this study suggested that TPACK may be conceived differently and this may promote new intervention programs to foster pre-service teachers' TPACK and design beliefs. TPACK-21CQL may open up new perspectives on how TPACK should be conceptualized, measured, and fostered. In addition, teachers' beliefs was recognized as an area that needed to be researched in conjunction with teachers' TPACK as these constructs are closely intertwined in influencing teachers' instructional decision-making. In particular, teachers' design beliefs have been identified as a multidimensional construct that is associated with teachers' TPACK, and teachers' design beliefs may predict the teachers' TPACK. Conclusively, to promote 21st century learning, educators need to create and validate specific instruments to investigate relations among psychologically and pedagogically relevant factors and the effectiveness of the instruction, address teachers design beliefs, create transformative TPACK and to address concurrently teachers' educational practices and associated beliefs. Finally, more research on how TPACK can be conceptualized and enacted is needed (Chai et al 2018, p.21). Teachers psychological and design beliefs are not the same everywhere yet they affect teachers' perception of TPACK. There is need to separate participants according to exposure to technological pedagogical knowledge and ICT tools. One could have Information Technology Knowledge but does not know how to easily apply it in pedagogy. Furthermore, TPACK may be conceived differently by different people, hence need for studying participants perceptions before testing and validating instruments

ICT is not yet fully integrated in classrooms especially in areas where technology is low, and further still there are no tools for ICT in many learning environments. Most testing and validations have been quantitative. Let there be a qualitative testing of TPACK? TPACK is conceived differently by teachers and the answers from questionnaires are influenced by this conception of TPACK. So more research on how TPACK can be conceptualised and enacted is needed.

However, all the studies (Valtonen 2018, Hasniza and Tenguku 2016, Kirayi 2016 and Chai 2018) reviewed, had pre-service science teachers as the participants. Therefore, more work on the TPACK framework needed to be done among in-service teachers and higher education faculty. Also, the studies reviewed suggested a bias in favour of the developed world, such as Malaysia (Haznisa & Tengku 2016), Finland (Valtonen et al., 2018); and Turkey (Kirayi 2016). In addition, some studies discovered that despite the emergence of the TPACK framework, the state of technology integration in classrooms had not been transformed and the central TPACK being multidimensional could have different ways of perceiving it and there was a need for 21st century competencies (Chai 2018). Further, the results of the studies reviewed indicated gaps in context. (Kirayi 2016) contended that TPACK changed with groups and their exposure, infrastructure / ICT tools availability and TPACK conceptualisation. More significantly, the Confirmatory Factor analyses in these studies showed that the tested instruments fit the TPACK framework though with differences in each study in spite of all the studies being on pre-service science teachers TPACK. For example, Kirayi 2016, confirmatory factor analysis registered significant differences between the bottom and top groups; thus showing the sufficiency of the items' discriminatory powers. As a result of those analyses, the scale proved to have the necessary properties required for measuring the TPACK self-efficacy perceptions of pre-service science teachers. On the other hand, Chai's (2018) CFA indicated that teachers' beliefs need to be researched in conjunction with teachers' TPACK as these constructs are closely intertwined in influencing teachers' instructional decision-making. This implies that TPACK could be conceived differently and thus opening up new perspectives on how TPACK should be conceptualised, measured, and fostered. Hasniza et. al (2016) TPACK model implied a lack of adequate understanding of TPACK hence poor use of ICT in classroom. Such gaps prompted the current study to test the validity and reliability of the constructs in the TPACK framework in the context of the teachers of quantitative disciplines in Makerere University in Uganda, a developing country.

Abbit (2011) aimed at review of literature to examine the emerging methods and instruments designed to assess the technological pedagogical content knowledge of pre-service teachers. It examined the development of TPACK in teacher preparation programmes in an effort to highlight emerging instruments and methods available for this group; the challenges, purposes and potential use of these tools for TPACK – based evaluations of pre-service teachers' preparation experiences. It unearthed efforts undertaken to develop valid and reliable tools for assessing teacher knowledge as represented by the TPACK framework. This was done through compilation of lists of journal articles and conference papers in reference to TPACK framework especially those that used measurement of TPACK in the context of teacher preparation. Unfortunately many conference papers on TPACK did not describe a specific method or procedure of measuring components of the TPACK framework. The specific procedures included quantitative and qualitative approaches to assessing knowledge in the TPACK domains. However, this review was limited in scope on measures of technological, pedagogical content knowledge of teacher preparation and in peer –reviewed article journals. He asserted that the challenge of measuring TPACK of pre-service teachers in a variety of ways that present both the difficulty in understanding how teacher knowledge influences actual teaching practices and the over-arching challenge of efficiency, reliability and validity of the measurement. Secondly, there were largely qualitative research efforts to define TPACK until Mishra and Koehler's (2006) quantitative survey instrument of 7 – point Likert scale to measure participants' thought about online learning. Additionally, this survey focused much on cognitive processes with need from a respondent to agree or disagree with statements. The results indicated the importance of the context. The instruments identified were self –reporting measures and performance –based TPACK measures. Abbit maintained that sensitivity to the context in which pre-service teachers learn about technology, pedagogy and content limit the scope of assessment methods or instruments to a specific course or learning environment. Therefore, the study called for use of multiple instruments to maintain the context sensitivity necessary to examine specific learning experiences.

Fisser et. al (2015) discussed researchers' and teacher educators' views on TPACK and described the instruments to measure it. In the review, the conceptual historical development of TPACK from TPACK was highlighted and how different studies have been adding correlations like context, Venn diagrammatic adaptations to illustrate interdependence to the desire to measure whether teachers have sufficient TPACK and whether growth can be measured or not. These identified how different types of measurement instruments have been employed by different studies namely; self-assessment survey, classroom observation and assessment of artifacts and how measurement of TPACK is dependent on researchers or teacher educators' views. Some studies reviewed showed domains of TPACK being an integrated whole while others were technological enhancements of PCK and other construct which greatly affect the way TPACK is measured. Some studies recognised seven constructs. These noted that literature on instruments has been majorly categorised into self- assessment surveys and performance- based assessments with a focus on lesson planning, teachers' classroom performance and performance based on specific tasks. Examples of these given are Schmidt's Self – perception of TPACK based on 5-point Likert scale with seven domains and Harris, Grandgenett and Hofer which provided an example of performance- based TPACK instrument. The latter studies provided a 3- 5-point Likert scale. The limitations of the instruments that can be used in all contexts, tend to be general in nature and the drawback of TPACK –specific contexts was that diversity and other factors tend to play a crucial role in effective technology integration in education, like teacher attitude and beliefs on technology. When used in combination, over along span of time, instruments give a good indication of someone's TPACK development, practically meaning that instruments from TPACK framework could be used to measure TPACK and give feedback on teacher's development when it came to effective technology integration.

Luik, Taimalu, & Suviste (2018) undertook a study that developed a generally acceptable instrument for measuring TPACK. The study aimed at validating the created instrument and finding out pre- service teachers' perception of the Technological, Pedagogical and Content Knowledge regarding the TPACK framework in Estonia where technology is broadly used in general education contextually. Additionally, the paper reviewed literature on Knowledge domains, measurement of teacher knowledge using the TPACK framework and previous teacher knowledge according the TPACK framework. The instrument used in this study measured self – reported knowledge. First, items from different studies were composed and specifically translated in Estonian language with a 5-point Likert scale. Several papers which dealt with developing valid and reliable instruments for measuring teacher evaluations of their knowledge according to the TPACK model in different countries were reviewed, for example, in Singapore, Taiwan, China, Ghana, Turkey and USA but found out that more studies of teachers from different countries were still needed to explore cultural differences in TPACK perceptions among pre-service and in-service and in-service teachers. Studies on student perceptions of college teacher knowledge according to the TPACK framework were reviewed. Some of these studies investigated teacher perceptions using TPACK framework from different subject areas and some had constructed TPACK instruments for teachers with similar content backgrounds, English as Foreign Language teachers, for Physical Education, Science teachers and Secondary school teachers. Particularly, Schmidt, et al, 2009 developed a scale where CK was divided into different subjects, viz; Literacy, Mathematics, Science and Social studies; translated in different countries. Most of these studies reviewed used a 5- Point Likert scale; and even a scale of 0 -100 have been used. It was noted that because these self- reported questionnaires do not measure real Knowledge levels, results obtained with these instruments were called Teacher Framework or Teacher Opinions on teacher TPACK self-efficacy. Some of the studies reviewed only used theory-based factors constructed without exploring the construct validity of the instrument. Still, in many papers reviewed, the exploratory factor analysis (EFA) and confirmatory structural equation models were used. These analyses yielded different structures of the TPACK framework and most had difficulty identifying the seven factors of the TPACK. The model with seven factors had been supported by some studies like Kazu and Erten (2014), Lin, et al (2013) and Pamuk, et al (2009). All these mentioned studies supported Mishra and Koehler (2006) framework. Some few studies reached a 10 – factor model consisting of TK, PK, PCK, TCK, TPK and TPACK and four separate factors of CK representing CK in Mathematics, Social Studies, Science and Literacy. Some studies had nine – factor structure but with some seven adopted parts of Mishra and Koehler (2006) framework and two were the teachers' constructivist beliefs and design disposition. However, these models indicate strong relationships between dimensions. In this study, it was found that out several studies indicated a greater or lesser number of factors than seven. In some studies original factors were merged together and it was found out pre-service teachers did not link CK to TPACK. Moderate to high correlations between all factors were found. In some studies reviewed, constructs were four, five, eight or nine. Some studies only items described TPACK as overlapping with all basic forms of Knowledge emphasising the importance of integrating the three parts. However, the study by Yurdakl et al (2012) indicated that the TPACK part itself has a four –factor structure: design (designing teaching in a way that all components are integrated), exertion (using technology in the teaching process and evaluating this process), ethics (technology related ethical issues) and proficiency (leadership ability to integrate technology).

Nordin and Arrifin (2016) asserted that several studies reviewed had acknowledged the need to develop a reliable and valid instrument in relation to measuring pre-service teachers' TPACK. Several TPACK surveys developed and tested on teachers were reported to be of high internal reliability. Studies have also tried to validate the TPACK instrument in different contexts. In that, there were different ways of measuring TPACK of pre-service teachers, e.g, conducting self-reporting surveys and technology integration assessment rubric and performance –based measurements like the individual task –based assessment.

Following the literature, several gaps can be discerned. For example, reviewers (Abbit, 2011; Fisser et al, 2015; Luik, Taimalu, & Suviste, 2018; Nordin and Arrifin, 2016) raised questions on the validity and/ or reliability of the TPACK framework and the instrument there from. In particular, Abbit (2011) observed that, with regard to the measurement of TPACK, instruments identified were self –reporting measures and performance –based TPACK measures. These lack sensitivity to the context in which pre-service teachers learn about technology, pedagogy and content limit the scope of assessment methods or instruments to a specific course or learning environment. Therefore, the study called for use of multiple instruments to maintain the context sensitivity necessary to examine specific learning experiences. Fisser et al (2015) say; the limitations of the instruments that can be used in all contexts, tend to be general in nature and the drawback of TPACK –specific contexts was that diversity and other factors tend to play a crucial role in effective technology integration in education, like teacher attitude and beliefs on technology. When used in combination, over along span of time, instruments give a good indication of someone's TPACK development, practically meaning that instruments from TPACK framework could be used to measure TPACK and give feedback on teacher's development when it came to effective technology integration. However, Luik, Taimalu, & Suviste (2018) noted that these models indicated strong relationships between dimensions and in some studies reviewed, constructs were four, five, eight or nine. Some studies only items described TPACK as overlapping with all basic forms of Knowledge emphasizing the importance of integrating the three parts. Nordin and Arrifin (2016) asserted that several studies reviewed had acknowledged the need to develop a reliable and valid instrument in relation to measuring pre-service teachers' TPACK. Several TPACK surveys developed and tested on teachers were reported to be of high internal reliability. Studies have also tried to validate the TPACK instrument in different contexts. In that, there were different ways of measuring TPACK of pre-service teachers, e.g, conducting self-reporting surveys and technology integration assessment rubric and performance –based measurements like the individual task–based assessment. In an attempt to narrow such gaps, the current study sought first, to establish the validity and reliability of each of the seven constructs of TPACK. Second, to test whether the seven constructs were independent. Third, to re-examine whether the seven-factor TPACK framework was reasonable.

Research Questions

The research questions posed for this study were

1. To what extent were each of the seven constructs of TPACK valid and reliable?
2. To what extent were the seven constructs of TPACK independent?
3. To what extent was the seven-factor TPACK framework reasonable?

Methodology

Sampling technique and sample

Using a cross-sectional survey design, data were collected from a sample of 87 chosen from among 500 academic staff teaching quantitative disciplines in Makerere University. The sampling strategy used involved simple purposive random sampling, whereby every teacher of the quantitative Mathematical discipline had equal chance of responding to the questionnaire irrespective of age or tenure. It was purposive in that it focussed only teachers of quantitative Mathematical disciplines than other disciplines. Makerere University was chosen for being the first and oldest with the public University. The term "quantitative disciplines" was taken to be broad and thus included a range of disciplines where quantitative skills are useful. Such disciplines included Science, Technology, Engineering and Mathematics (STEM) disciplines and their offshoots like Accounting, Chemistry, ICT, Measurement and Evaluation, Psychometrics, and Quantitative Data Analysis. Regarding age groups, the majority (61.8%) of the respondents were aged 30 but below 40 years, followed by those (23.5%) who were at least 40, while the rest (14.7%) were at most 30 years of age.

In terms of gender, the males (79.3%) dominated the females (20.7%). With respect to tenure, the majority (47.6%) of the respondents had served for below five years as a lecturer at university level; followed by those (26.8%) who had served five to 10 years; and a few others (25.6%) had served 10 years and above. On the question of highest academic qualification, the majority had a Masters degree (56.3%), followed by those with Doctorates (36.8%), and a few others with Bachelor degrees (6.9%). In terms of academic ranks, the respondents were distributed as follows: majority were Assistant Lecturers (50.6%) followed by Lecturers (24.1%), Senior Lecturers (13.8%) and Teaching Assistants (6.9%), Associate Professors (3.4%), and Professors (1.1%).

Instrument

The instrument used in the study had the seven knowledge constructs as suggested by the TPACK framework, with a number of items for each construct adapted from a respectable source as shown in Table 1. As Schmidt et al. (2009), Chai, Chin, Koh and Tan (2013) and Chai, Ng et al. (2013) had done, the items being attitude or opinion items, were measured using Likert five-point ranked scale ranging from 1 (Strongly disagree) to 5(Strongly agree).

Data Analysis

The validities of multi-item constructs of TPACK (i.e. CK, PK, TK, PCK, TPK, TCK & TPACK), were tested using confirmatory factor analysis (CFA), while their reliabilities were tested using the Cronbach alpha method. Correlation analysis was carried out to establish whether the constructs were independent. Finally, exploratory factor analysis (EFA) helped with the re-assessment of the seven-factor structure of TPACK.

Results

Research Question 1: To what extent was each of the seven constructs of TPACK valid and reliable?

The first objective of the study was to establish the validity and reliability of the measure for each of the seven constructs of the TPACK framework. This was achieved via confirmatory factor analysis (CFA) on the items on each construct. The Kaiser rule or criterion (Kaiser, 1960 cited in Mvududu & Sink, 2013, p. 86) that stipulates that factors with eigenvalues greater than one be considered significant, was used in the study. For a given factor loading, 0.5 (Costello & Osborne, 2005) was used as the minimum. For reliability tests, a benchmark of $\alpha = 0.7$ (Tavakol & Dennick, 2011) for the Cronbach alpha was set. The results are as presented in the subsequent tables (Tables 2 through 8).

Content Knowledge

According to Table 2, CFA reduced the three items of the first domain of knowledge, namely content knowledge (CK) in the TPACK framework to the ideal situation of one factor. The factor had an eigenvalue of 2.373, meaning that the factor accounted for 2.373/3 x 100 = 79.1% of the total variance among the three items. The loadings of the respective items on the factor are also given in Table 2.

Table 2. Loadings on the Factor on Content Knowledge.

Items	Descriptions	Loadings	Cronbach α
CK1	I have sufficient knowledge about quantitative literacy relevant to what I lecture	0.904	0.861
CK2	I can use the quantitative way of thinking whenever lecturing	0.871	
CK3	I have various strategies of developing my quantitative literacy	0.893	
	Eigenvalue	2.373	
	%variation explained	79.1	

Considering loadings of at least 0.5 as being high, then Table 2 suggests that all the three items (CK1 – CK3) loaded highly on the factor. Hence all of them were valid items of CK. Their reliability (Cronbach alpha, α) was 0.861, implying that they were also reliable measures of CK.

Pedagogical Knowledge

According to Table 3, CFA reduced the seven items of the second knowledge domain, namely pedagogical knowledge (PK) in the TPACK framework to two factors, i.e., PK1 and PK2. PK1 had an Eigen value of 3.211, meaning that the factor accounted for 3.211/7 x100 = 45.9% of the total variance among the seven items. PK2 had an Eigen value of 1.157, meaning that it accounted for 1.157/7 X 100 = 16.5% of the total variance of the seven items.

Table 1 . Constructs, number of items adapted for each, their sources and reliability.

Construct	Number of items adapted	Source of instrument, total number of items and reliability (α-values)
Content (CK)	3	Schmidt et al. (2009), 3 items (α = 0.85)
Pedagogical (PK)	7	Schmidt et al. (2009), 7 items (α = 0.84)
Technological (TK)	7	Schmidt et al. (2009), 7 items (α = 0.82)
Pedagogical Content (PCK)	5	Chai, Ng et al. (2013), 5 items (α = 0.92)
Technological Pedagogical (TPK)	4	Chai, Chin et al. (2013), 4 items (α = 0.92)
Technological Content (TCK)	4	Chai, Ng et al. (2013), 4 items (α = 0.90)
Technological Pedagogical Content (TPACK)	6	Chai, Ng et al. (2013), 6 items (α = 0.92)

Table 3. Loadings on the Factor on Pedagogical Knowledge.

Items	Descriptions	Factor 1	Factor2	Cronbach α
PK1	I have adequate knowledge on how to assess student performance	0.1	0.872	0.717
PK2	I can adapt my lecturing based upon what students currently do not understand	0.213	0.805	
PK3	I can adapt my lecturing style to different learner types	0.495	0.654	
PK4	I can assess student learning in multiple ways	0.594	0.415	
PK5	I can use a wide range of lecturing approaches	0.756	0.158	
PK6	I am familiar with common student understandings and misconceptions in my discipline	0.646	0.272	
PK7	I know how to organize and maintain a conducive lecture environment	0.792	-0.028	
	Eigenvalue	3.211	1.157	
	% variation explained	45.9	16.5	

The loadings of the respective items on the factor are also given in Table 3. Considering loadings of at least 0.5 as being high, then Table 3 suggests that the first three items (PK1- PK3) had low loadings, only the last four items (PK4 – PK7) loaded highly on the first factor. Hence, the four of seven items were valid items of PK. Their reliability (Cronbach alpha, α) was 0.717, implying that the four items were reliable measures of PK.

Technological Knowledge

According to Table 4, CFA reduced the seven items of the third domain of knowledge, namely technological knowledge (TK) in the TPACK framework to the ideal one factor. The factor had an eigenvalue of 5.29, meaning that the factor accounted for 75.6% of the total variance among the seven items. The loadings of the respective items on the factor are also given in Table 4. Considering loadings of at least 0.5 as being high, then Table 4 suggests that all the seven items (TK1 – TK7) loaded highly on the factor. Hence all of them were valid items of TK. Their reliability (Cronbach alpha, α) was 0.945, implying that they were reliable measures of TK too.

Table 4. Loadings on the Factor on Technological Knowledge.

Items	Descriptions	Loadings	Cronbach α
TK1	I know how to trouble shoot technical problems that arise while I am lecturing	0.883	0.945
TK2	I easily learn to use technology for lecturing	0.883	
TK3	I keep up with important new technologies for lecturing	0.875	
TK4	I easily play around with technology while lecturing	0.878	
TK5	I know a lot about different technologies for lecturing	0.854	
TK6	I have the technical skills I need to lecture with technology	0.864	
TK7	I have had sufficient opportunities to lecture with different technologies	0.848	
	Eigenvalue	5.29	
	% variation explained	75.6	

Pedagogical Content Knowledge

According to Table 5, CFA reduced the five items of the fourth domain of knowledge, namely pedagogical content knowledge (PCK) to the ideal one factor. The factor had an Eigen value of 3.24, meaning that the factor accounted for 64.8% of the total variance among the five items. The loadings of the respective items on the factor are also given in Table 5. Considering loadings of at least 0.5 as being high, then Table 5 suggests that all the five items (PCK1–PCK5) loaded highly on the factor. Hence all of them were valid items of PCK. Their reliability (Cronbach alpha, α) was 0.858, implying that they were reliable measures of PCK too.

Table 5. Loadings on the Factor on Pedagogical Content Knowledge.

Items	Descriptions	Loadings	Cronbach α
PCK1	Without using technology, I can help my students to understand the content of my discipline through various ways	0.765	0.858
PCK2	Without using technology, I can address the common learning difficulties my students have for my discipline	0.905	
PCK3	Without using technology, I can facilitate meaningful discussion among my students about the content in my discipline	0.824	
PCK4	Without using technology, I can engage students in solving real world problems related to my discipline	0.749	
PCK5	Without using technology, I can support students to manage their learning of my discipline	0.770	
	Eigenvalue	3.24	
	% variation explained	64.8	

Technological Pedagogical Knowledge

According to Table 6, CFA reduced the four items of the fifth knowledge domain, namely technological pedagogical knowledge (TPK) to the desired one factor. The factor had an Eigen value of 3.12, meaning that the factor accounted for 77.9% of the total variance among the four items. The loadings of the respective items on the factor are also given in Table 6. Considering loadings of at least 0.5 as being high, then Table 6 suggests that all the four items (TPK1–TPK4) loaded highly on the factor. Hence all of them were valid items of TPK. Their reliability (Cronbach alpha, α) was 0.904, implying that the four items were reliable measures of TPK too.

Technological Content Knowledge

According to Table 7, CFA reduced the four items of the sixth domain of knowledge, namely technological content knowledge (TCK) to one factor. The factor had an Eigen value of 3.24, meaning that the factor accounted for 80.9% of the total variance among the four items. The loadings of the respective items on the factor are also given in Table 7. Considering loadings of at least 0.5 as being high, then Table 7 suggests that all the four items (TCK1–TCK4) loaded highly on the factor. Hence all of them were valid items of TCK. Their reliability (Cronbach alpha, α) was 0.921, implying that the four items were also reliable measures of TCK.

Table 6. Loadings on the Factor on Technological Pedagogical Knowledge.

Items	Descriptions	Loadings	Cronbach α
TPK1	I am able to facilitate my students to use technology to find more information on their own	0.894	0.904
TPK2	I am able to facilitate my students to use technology to plan and monitor their own learning	0.908	
TPK3	I am able to facilitate my students to use technology to construct different forms of knowledge representation	0.905	
TPK4	I am able to facilitate my students to collaborate with each other using technology	0.821	
	Eigenvalue	3.12	
	% variation explained	77.9	

Table 7. Loadings on the Factor on Technological Content Knowledge.

Items	Descriptions	Loadings	Cronbach α
TCK1	I can use the software that are created specifically for my discipline	0.902	0.921
TCK2	I know the technologies available for research for content in my discipline	0.884	
TCK3	I can use appropriate technologies to present the content of my discipline	0.935	
TCK4	I can use specialized software to perform inquiry about my discipline	0.876	
	Eigenvalue	3.24	
	% variation explained	80.9	

Technological Pedagogical Content Knowledge

According to Table 8, CFA reduced the six items of the seventh and last knowledge domain, namely technological pedagogical content knowledge (TPACK) in the TPACK framework to the ideal one factor. The factor had an Eigen value of 4.02, meaning that the factor accounted for 67.0% of the total variance among the six items. The loadings of the respective items on the factor are also given in Table 8. Considering loadings of at least 0.5 as being high, then Table 8 suggests that all the six items (TPACK1 – TPACK6) loaded highly on the factor. Hence all of them were valid items of TPACK. Their reliability (Cronbach alpha, α) was 0.901, implying that the six items were also reliable measures of TPACK.

Research Question 2: To what extent were the seven constructs of TPACK independent?

The second objective of the study was to test whether the seven knowledge constructs in the TPACK framework, namely Content Knowledge (CK), Pedagogical Knowledge (PK), Technological Knowledge (TK), Pedagogical Content Knowledge (PCK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK) and Technological Pedagogical Content Knowledge (TPACK) were independent. Average indexes were computed for the valid items of the respective constructs. Table 9 (correlation matrix) suggests that many constructs were significantly correlated. Apart from (CK and TK; CK and TPK; CK and TCK; CK and TPACK; PK and TK; PK and TPK, PK and TCK, PK and TPACK; PCK and TPK all the other pairs of constructs were correlated ($p<0.05$) and some highly ($p< 0.01$).

Research Question 3: To what extent was the seven-factor TPACK framework reasonable?

The third and last objective in the study was to re-examine whether the TPACK framework (Mishra & Koehler, 2006) as being made up of the seven constructs (CK, PK, TK, PCK, TPK, TCK & TPACK) was reasonable. Exploratory factor analysis (EFA) reduced the 36 items in the TPACK instrument (Tables 2 - 8) into as many factors. However, as Table 10 suggests, only the first seven factors were significant since they had Eigen values ranging from 12.97 (maximum) to 1.11 (minimum) that exceeded 1.00. These factors explained from 36.03% (maximum) to 3.07%

Table 8. Loadings on the Factor on Technological Pedagogical Content Knowledge.

Items	Descriptions	Loadings	Cronbach α
TPACK1	I can formulate in-depth discussion topics in my discipline and facilitate students' online collaboration with appropriate tools	0.845	0.901
TPACK2	I can set authentic problems related to topics in my discipline and present them through technology to engage my students	0.806	
TPACK3	I can facilitate students' construction of knowledge in my discipline using appropriate technologies according to the requirements of the syllabi	0.829	
TPACK4	I can create technology-supported self-directed learning activities specifically for my discipline	0.825	
TPACK5	I can design inquiry-based learning supported by appropriate technologies to guide students in understanding knowledge related to my discipline	0.794	
TPACK6	I can design student-centered learning that integrates knowledge of my discipline, technologies and pedagogies	0.813	
	Eigenvalue	4.02	
	% variation explained	67.0	

Table 9. Inter-correlations of the TPACK Constructs.

	CK	PK	TK	PCK	TPK	TCK	TPACK
CK		0.546**	-0.141	0.547**	-0.143	-0.086	-0.026
PK			-0.025	0.532**	0.145	0.032	0.047
TK				-0.334**	0.658**	0.844**	0.712**
PCK					-0.10	-0.312**	-0.235*
TPK						0.665**	0.665**
TCK							0.767**
TPACK							

*Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

Table 10. Factors, their eigenvalues, % variance explained and highly loading items.

Factor	Eigenvalue	% variance	Highly loading items (loading in brackets)
1	12.97	36.03	TK1 (0.882); TK2 (0.827); TK3 (0.803); TK4 (0.771); TK5 (0.814); TK6 (0.818); TK7 (0.758); *TPK1 (0.546); TCK1 (0.783); TCK2 (0.777); TCK3 (0.778); TCK4 (0.633); TPACK1 (0.558);TPACK2 (0.511)
2	6.83	18.97	TPACK1 (0.512); TPACK2 (0.504); TPACK3 (0.601); TPACK4 (0.696); TPACK5 (0.785); TPACK6 (0.727)
3	2.54	5.98	PCK1 (0.726); PCK2 (0.795); PCK3 (0.777); PCK4 (0.611); PCK5 (0.757)
4	1.48	4.11	CK1 (0.802); CK2 (0.801); CK3 (0.815)
5	1.24	3.45	*TPK1 (0.710); TPK2 (0.807); TPK3 (0.741)
6	1.19	3.29	PK5(0.831); PK6 (0.572); PK7 (0.507)
7	1.11	3.07	PK7 (0,519); TPACK2 (0.525)

Footnote: The item prefixed with a symbol (*TPK1 in the first and fifth factor) cross-loaded and hence was dropped for complexity

(minimum) respectively of the joint variation in the 36 items. The items with high factor loadings (of at least 0.5) are given in Table 10 after a Varimax rotation, as recommended by Yong and Pearce (2013, pp. 84, 86).

The question was: Was the TPACK framework as suggested by Mishra and Koehler (2006) discernible in Table 10? Table 10 suggests that the constructs of TK (TK1 - TK7) and TCK (TCK1 - TCK4) in addition to TPK1, TPACK1 and TPACK2 loaded highly on the first factor and hence most significant factor as its valid items. This suggested that TK (TK1 –TK7) and TCK (TCK1 – TCK4) loaded together on the first and hence the most significant factor as its valid items. This suggested that the TK and TCK constructs were not distinct knowledge domains. The item TPK1 cross-loaded on the first and fifth factors, and hence was complex and dropped (Moore & Benbasat, 1991, p. 207). The second, third, fourth, fifth, sixth and seventh factors in descending order of importance, supported the TPACK, PCK, CK, TPK, PK and PK domains. In summary, the TPACK structure as suggested by Mishra and Koehler (2006) could to a great extent be discerned in Table 10.

Discussion

The first objective in the study was to establish the validity and reliability of each of the seven constructs (CK, PK, TK, PCK, TPK, TCK & TPACK) in Mishra and Koehler's (2006) TPACK framework. Confirmatory factor analysis, CFA (Tables 2 - 8) showed that the tested constructs of TPACK in these studies was in line with the TPACK framework advanced by Koehler and Mishra (2009) and the TPACK was simulated from the data set used in this study. The result was similar to that of other studies like Valtonen 2018, Hasniza et al 2016, Kirayi 2016 and Chai et al 2018 where the CFA tended to align with the TPACK framework. The findings supported the submission by the above named researchers to the effect that, TPACK is a validly tested instrument to measure teachers' TPACK. In table 8 for instance, the six factors of TPACK were reduced to the one ideal factor highly loaded with 67.0% Eigen values and all the other items loaded highly on the factor. The Cronbach alpha, α was 0.901, implying that the six items were also reliable measures of TPACK. In this regard, the finding based on CFA implied that TPACK is a reasonable framework which researchers should continue using confidently.

The second objective in the study was to test whether the seven constructs of TPACK were independent. The results of Pearson correlation analysis, PLC (Table 9) suggested that most of the constructs were inter-related. The finding was in line with Archambault and Barnett (2010), who also found strong correlations between CK, PK, TPK, TCK and TPACK construct. It was at par with Bilici et al. (2013) who showed that there were high correlations between TPACK, TK, TCK, TPK, and PCK. However, the finding based on PLC put into question whether the constructs in TPACK are really measuring different things, which provides ground for research for future researchers. It could also imply that when carrying out a study using the constructs of TPACK as explanatory variables in a multiple regression model, the researcher does not have to include all of them. Else the model will suffer multi-collinearity (Sweet & Grace-Martin, 2003).

The third and last objective of the study was to re-examine whether the TPACK framework as made up of the seven constructs (CK, PK, TK, PCK, TPK, TCK & TPACK) was reasonable. Exploratory factor analysis, EFA (Table 10) showed that the TPACK framework as suggested by Mishra and Koehler (2006) could not fully be replicated using our data set. TK and TCK loaded together and hence were not distinct constructs. The result was in line with several earlier studies (e. g. Ritzhaupt et al., 2016; Valtonen et al., 2015) whereby EFA tended not to support the TPACK framework. This lends a lot of support to authors such as Graham who contend that, "many researchers who have made serious attempts at measuring TPCK constructs have been challenged by the difficulty… in distinguishing… between the constructs" (p. 15).

In particular, the items on TK loaded together with those of TCK. This was in line with Graham (2011) who observed that the TK construct in TPACK is fuzzy. Also, Graham observed that,

defining what is meant by technological knowledge [TK] is an example of the current lack of clarity in the TPACK framework.... The definition of technology has failed to clearly delineate the scope of TPACK.... [It results partly because] Koehler and Mishra (Koehler & Mishra, 2008; Mishra & Koehler, 2006) did not distinguish between the types of technology encompassed within TK. They included older technologies like pencil and chalkboard as well as newer digital technologies (p. 10).

The finding of TK and TCK loading together, that is, of TCK not being distinct, was in line with Shinas et al. (2013) who asserted that, "literature... indicates... difficulty with conceptualising TCK as a distinct knowledge domain" (p.351). However, the finding of TK and TCK loading together was in contrast with other studies, such as Archambault and Barnett (2010) , who in their study, found that, "the only clear dimension that distinguish[ed] itself is that of... TK" (p. 1656).

The PK, TPACK, PCK, TPK and CK constructs in that order of importance, were distinct. The finding that TPACK was distinct was at variance with the assertion by Voogt et al. (2012) to the effect that, "there is no agreement on what TPACK is" (p. 11). The finding that PCK was a distinct construct contrasted sharply with Graham (2011) who contended that, "while PCK has been heavily researched..., much debate continues regarding how to define the construct and [to] distinguish it from related constructs" (p.11). It was also at variance with Voogt et al. (2012) who claimed that, there was "no universal agreement what PCK entails" (p. 11). Never the less, the finding based on EFA to effect that the TPACK framework to a large extent could be replicated in the study, suggests that researchers could still use the TPACK framework, although efforts to refine it have to go on since in this study it was found not to be perfect.

Conclusion

This study was interested in an instrument based on the TPACK framework and tested the validity and reliability of its constructs in the context of the teachers of quantitative disciplines in Makerere University. The study was among the very first to report findings on the validity and reliability of the TPACK framework in the context of a developing country. Confirmatory factor analysis (CFA) established that the seven constructs of TPACK were valid. However, Pearson correlation suggested that the constructs were highly inter-correlated. Exploratory factor analysis (EFA) revealed that the TPACK framework could to a great extent be replicated using our data set. In particular, while the items on TK loaded together with those of TCK, the respective items of PK, TPACK, PCK, TPK and CK in that order of importance, were distinct constructs. That the TPACK framework could to a great extent be discerned from the data, suggests that researchers could still use the TPACK framework, although efforts to refine it have to go on. The study had limitations. Obviously, the sample scope was limited. More studies on the validity and reliability of TPACK could be carried out among other teachers in the same university than those of quantitative disciplines. Studies could be extended to other Universities in Uganda and beyond.

Recommendations

1. Basing on confirmatory factor analysis (CFA), TPACK is a reasonable framework which researchers should continue using with confidence.
2. Basing on Pearson Linear Correlation (PLC), the constructs of the TPACK framework are highly inter-correlated which researchers should check when using multiple regression, else their models will suffer multi-collinearity.
3. Basing on exploratory factor analysis (EFA), the TPACK framework could to a great extent be discerned from the data and researchers could still use it, although efforts to refine it have to go on.

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