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Research Article

Building Mathematics Teachers' TPACK Through Collaborative Lesson Design Activities

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Abstract

Developing teachers' competencies in technology integration has recently been one of the areas of attention in teacher training. This paper presents an investigation of the development of mathematics teachers' technological pedagogical content knowledge (TPACK) through collaborative lesson design activities. The study employed a pre and post-test for non-equivalent groups quasi-experiment with three groups. Participants were secondary school mathematics teachers from Dar es Salaam -Tanzania who responded to a TPACK questionnaire before and after the intervention. Group 1 participated in collaborative lesson design teams to integrate technology and implemented the designed lesson in the classroom. Group 2 participated in lesson planning and implementation and group 3 operated conventionally. Using paired sample t-test, although all groups appear to have improved their TPACK significantly, the effect size was large for group 1 and group 2 only. When the comparison between groups and across the two points of time for data collection was done using the split-plot analysis of variance, it was found that group 1 improved the most in TPACK. These finding favoured the use of collaborative lesson designs in school-based teacher design teams. The study recommends that professional development needs to be authentic by involving teachers in routine professional activities, optimizing their peer teams to support each other within the real school contexts.

Keywords: collaborative activities, lesson design, TPACK, mathematics education, professional development

INTRODUCTION

Technology integration in education is a widely investigated field. Many researchers are not only interested in the educational potential of technology in transforming classroom practices but also in ways teachers can effectively integrate technology for such transformation. The former, to result in positive effects depends on the latter. For example, the belief that technology access influences teachers' development of skills to transform classroom practices has made many governments invest significantly in projects to improve access to technology hardware in schools (Uslu & Usluel, 2019). Although the usefulness of technology is agreed

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and supported by many researchers (Niess, 2015), many of these researchers believe that the success of technology integration depends on multiple factors (Daya & Laher, 2019; Farjon et al., 2019; Nelson et al., 2019; Niess, 2015). Central to these considerations are teacher factors since teachers play a decisive role in the integration of technology (Agyei & Voogt, 2010; Drijvers, 2015).

Teachers' ability to facilitate learning using technology has been the focus of many teacher training programmes. College training plays a crucial role in developing teachers' abilities in the integration of technology in their teaching (Chukwuemeka et al., 2019; Nelson et al., 2019). However, as with any teacher knowledge, continuous professional development enables teachers to update and build new knowledge and skills to meet the contemporary needs for education. This is more important when technology integration is concerned. Despite increasing access to technology (Farjon et al., 2019; Mtebe et al., 2016) mere access and simple use do not lead to effective technology integration in teaching (Farjon et al., 2019). This paper discusses one of such factors that contribute to effective technology integration in instruction. However, it is worth noting that technology development is marked with rapid growth and changes, and this challenges teachers to keep pace with such rapid changes (Koh, 2019).

Although teacher education plays a significant role in developing teachers' skills regarding technology integration (Koh, 2019), some practicing teachers are actually digital immigrants. A good number of teachers were trained during the time when the technology for instruction was not well integrated into teacher education by ether practice or policy (Chesley & Jordan, 2012; Nelson et al., 2019). This problem does not only affect experienced teachers alone but also novice teachers who may be considered as digital natives. Farjon et al. (2019) explained that even new generations of teachers face challenges in facilitating instruction effectively with technology. Kafyulilo and Fisser (2019) contend that even in the current initial teacher education, opportunities to training for effective technology integration such as exposure to collaborative design activities are limited. As such professional development plays an important role not only in updating technology integration knowledge but also in enabling digital immigrants to cope up with the current demands of transformation in education. In developing countries, and in particular the Tanzanian context, where technology integration is at its embryonic stages, and where many teachers were trained without or before the era of modern technology integration in teacher education, the need for professional development for such teachers is high. To our knowledge, from the Tanzanian context, little research has been done in this area. There are few studies that have involved in-service teachers (Kafyulilo et al., 2013) and preservice teachers (Kafyulilo et al., 2015) in design-based activities for science and mathematics teachers. Other studies (Kihoza et al., 2016; Mtebe & Raphael, 2018) have surveyed the TPACK levels of teachers and reported moderate results. Also, with a focus on content knowledge, Mtebe et al. (2015) found that mathematics teachers tended to score less than science teachers with the majority not completing tasks in learning content using technology. Little can be found in the literature about the development of TPACK among practicing mathematics teachers in Tanzania. This paper contributes to fill this literature gap. As such, this paper discusses the development of TPACK for mathematics teachers in Dar es Salaam - Tanzania.

The TPACK Framework

The study employed the TPACK framework developed by Koehler and Mishra (2009). The TPACK framework advances the Pedagogical content knowledge (PCK) conception by Shulman (1986) who attends to among others these two questions: in what ways are the knowledge of the subject matter and knowledge of general pedagogy related? and what are the best ways of enhancing the acquisition and development of teacher knowledge? to include ways of such relationships and enhancement with technology. Shulman, while appreciating the necessity of content knowledge, believes that for effective teaching mere knowledge of content does not suffice. It is urged that teachers must know both the subject matter (CK) and pedagogy (PK) and that the two do not operate in isolation but interact to form teacher's professional knowledge that Shulman referred to as PCK. The study on PCK has evolved and has resulted in different conceptualisation with regard to its components but many researchers seem to agree at least on student understanding, instructional strategies, and representations (Maniraho & Christiansen, 2015). Developing from PCK Koehler and Mishra (2009) adds technology knowledge (TK) forming three primary domains of teachers' knowledge. Similar to Shulman, Koehler and Mishra argue that the three do not operate in isolation but interact. For effective teaching and engaging learners with different needs, teachers need to know ways of teaching specific topics with relevant technology (Alemdag et al., 2019) hence the importance of understanding the way the three knowledge domains interweave together. The interaction of these three primary knowledge domains results in four other teachers' knowledge: Pedagogical content knowledge (PCK), Technological pedagogical knowledge (TPK), Technological content knowledge (TCK), and Technological pedagogical content knowledge [TPACK] (Mishra, 2019).

In exploring and developing teachers' knowledge for technology integration in instruction, numerous studies have adopted the framework which has proved to be useful in explaining the kind of knowledge teachers may need for effective technology integration (Mishra, 2019; Njiku et al., 2020a). However, the conceptualisation of the framework and definitions of its constructs is still a continuing discussion among researchers (Alemdag et al., 2019; Ocak & Baran, 2019).

In the efforts to further unpack the TPACK concepts, the context within which TPACK may be assessed or developed has also been given due importance. Technology access and use tend to be dictated by the availability of technological tools especially within teachers' understanding of the context they work in (Roussinos & Jimoyiannis, 2019) and teachers' ability to use them. Other factors such as educational policy (Roussinos & Jimoyiannis, 2019) and school regulations and support (Nelson et al., 2019; Roussinos & Jimoyiannis, 2019) may also influence technology integration. These factors tend to differ widely across educational settings. Probably because of this reason multiple researchers have approached the integration of technology with a focus on the context. This may have also led to the modification of the framework to include the context (see Mishra, 2019).

TPACK and Collaborative Lesson Design Activities

Numerous studies have been carried out to examine the development of TPACK among teachers. With most studies having been done in initial teacher education (Farjon et al., 2019; Mouza, 2016), technology integration courses have been used as ways of developing TPACK (Koh & Chai, 2014; Weber & Waxman, 2015). Lesson design activities have also been prevalent among pre-service teachers' development of TPACK endeavours. On the other hand, professional development programmes for practicing teachers that are intended to develop their integration of technology knowledge and skills have also been documented. Some studies (see for example Alemdag et al., 2019; Ocak & Baran, 2019) have used lesson design activities that have also been seen to be effective. Activities used to develop TPACK from these courses differ widely but include the collaborative design of materials, discussion, and reflections (Alemdag et al., 2019; Koh & Chai, 2014), technology selection, curriculum planning, lesson preparations, and assessment (Ocak & Baran, 2019). Many of the studies in the area report design-based activities to be effective in developing teachers TPACK. It may thus seem that the effectiveness of each activity seems to depend on the level of relevance and engagement. As such, Koh (2019) discusses design scaffolds that may be used to develop TPACK among teachers. Scaffolds are meant to help teachers stepwise in various kinds of activities through which TPACK can be developed. Central to these scaffolds is the lesson design (Koh, 2019). Lesson design activities for both pre-service and in-service teachers seem to be one of the effective ways of developing teachers' TPACK (Kay, 2007).

Development of Mathematics Teachers' TPACK

Technology integration has received special attention in mathematics instruction. As highlighted earlier, the success of this integration highly depends on teachers' knowledge to effectively integrated technology in the classroom. Various studies have been carried out to investigate the development of mathematics teachers TPACK. For example, with the increasing access to technology especially mobile technologies, there has also been an increase in applications (apps). Some of these apps are multidisciplinary in nature while others are subject-specific. In mathematics as a discipline, there have also been numerous applications developed and may be useful for instruction (Handal et al., 2016). However, little research has been done to evaluate and hence guide the instructional use of the apps (Kiekel & Kirk, 2013). For this reason, researchers such as Handal et al. (2016) and Kiekel and Kirk (2013) evaluated the usefulness of mathematics mobile apps for instruction.

There is a need to help teachers integrate such apps in their teaching. This calls for professional development programmes that will enable school teachers to transform their teaching practices (Handal et al., 2016).

In understanding and developing mathematics teachers' competencies of teaching mathematics with technology, the TPACK has been one of the most useful frameworks. Getenet (2017) uses the TPACK framework to guide the study that investigated specific knowledge that mathematics teachers should have to effectively facilitate the learning of mathematics. Nelson et al. (2019) used the TPACK framework to investigate factors that influence technology integration among teachers and found that teachers' knowledge of technology and institutional support contributed greatly in facilitating the development of TPACK. Similarly, Handal et al. (2013) found factors related to instruction, curricular, and organisational support to affect teachers' TPACK and technology integration in general. Despite these efforts, evidence exists that teachers are not incorporating technology effectively in the teaching of mathematics (Crompton, 2015). This calls for efforts to develop teachers' competencies in technology integration.

Experiential learning, course delivery using technology, field placement, TPACK centred assignments, and journal writing are some of the activities researchers have used to develop TPACK among preservice teachers (Crompton, 2015). There has also been a shift from tecno-centric training where the focus was training teachers in using technology tools to content-centric where the focus is teaching particular content with some technology tools (Jaipal-Jamani & Figg, 2015). Jaipal-Jamani and Figg argue that the traditional technocentric model decontextualized learning, as such the authors advocate for collaborative learning thereby bringing together the rich connections of content, technology, and ways of teaching the content. Considering the diverse distribution of mathematics teachers that include both digital natives who may be very comfortable in technology use and digital immigrants who may be having sufficient experience in pedagogy, collaborative activities in lesson design teams (Kafyulilo et al., 2013; Kearsley & Shneiderman, 1998) were thought, in this study, to be effective in developing their TPACK. Also, considering the importance of the context (Mishra, 2019) with diverse access to resources within schools, school-based design teams were also used in the study. Teachers' active participation in lesson design activities that are authentic within the context enabling them to put into practice their developed TPACK (Alemdag et al., 2019) was essential to the study.

Research Questions

The study, therefore, investigated whether collaborative activities in lesson design teams would lead to improved TPACK among mathematics teachers in Dar es Salaam, Tanzania. The study responded to two research questions:

1. What is the change in mathematics teachers' self-reported TPACK before (Time 1) and after (Time 2) involvement in professional development activities?
2. What is the effect of mathematics teachers' involvement in professional development activities on their self-reported TPACK?

Hypotheses Tested

The study tested the following null hypotheses:

$H_0 1$ There is no significant change in mathematics teachers' self-reported TPACK from time 1 to time 2

$H_0 2$ Involvement in professional development activities does not affect mathematics teachers self-reported TPACK

METHODOLOGY

Participants

The study involved 125 secondary school mathematics teachers from the Dar es Salaam region of Tanzania. Participants had various teaching experiences ranging from 0 to more than 15 years. They were distributed across 38 secondary schools in the region. To select participants, multistage sampling was used. First, the region was selected purposively due to the fact that it leads in technology infrastructure in the country (Mtebe et al., 2011; Sife et al., 2010), a factor which was considered important for the quasi-experiment as it would provide more access to technological facilities. Then, cluster random sampling was used to obtain participants where the units of sampling were the schools as clusters. All mathematics teachers in the selected schools were requested to participate in the study. Of the 125 participant teachers, 45 were female and 80 were male. Preliminary analysis necessitated the exclusion of two outlying cases from the data file due to the violation of some statistical assumptions especially normality. As such the final number of participants whose information is reported in this paper is 123. All participants willingly agreed to participate in the study by filling in the consent forms.

The Design

The study was carried out to develop mathematics teachers' TPACK using lesson design and implementation as professional development activities. The pre- post-test for non-equivalent groups quasi-experiment (Scriven, 2014) was used as the study design. The quasi-experiment was designed to provide evidence of the effect of professional development activities on mathematics teachers' development of TPACK. Using the clusters, participants were distributed into three groups: group 1 (42 teachers) was involved in the collaborative lesson design activities in school-based design teams, group 2 (41 teachers) participated in the implementation of lessons with technology but without the design activities, group 3 (40 teachers) was merely for comparison purposes, hence operated conventionally.

The intervention: the intervention was central to a larger study that was designed to develop mathematics teachers TPACK and attitudes. In this paper, the focus was given to the TPACK development. The study was guided by the engagement theory (Kearsley & Shneiderman, 1998) which details the need for teachers to participate in learning activities that are authentic, active, and collaborative in nature. The intervention activities ran for two months from mid-March to mid-May 2019.

Group 1 activities:

1. Topic selection: Participants identified topics that would follow in their teaching timeline of the semester.
2. Analysis: Working in school-based groups, participants discussed available and accessible digital resources including both hardware and software, and their possible educational uses in relation to the identified topics. Online resources such as YouTube videos, drills, WebQuests, and mobile apps such as Shule Direct, tHL, and O-level Math Pro were identified.
3. Design: Participants collaborated in visiting online resources particularly YouTube mathematics videos and mobile apps. They also discussed ways of incorporating these resources into their lesson plans.
4. Development: Participants worked together in planning lessons that would involve the use of the identified resources. Some watched the video clips and planned to guide their learners to access them while others accessed content and assessment items from mobile apps and planned to guide their learners through the process of accessing and using them in their learning.
5. Implementation: Participants delivered the lesson in the classroom and were expected to follow their lesson plans.

Group 2 activities: This group was involved in two of the five activities done by participants of group 1. They were informed of the possible technologies that would be used as discussed in group 1. They were expected to participate in 4: the development and 5: implementation activities as detailed from group 1 activities. However, they were not required to work in collaborative teams.

Group 3 activities: This group did not participate in the intervention activities for experimental purposes of comparison. Participants continued to teach as per their teaching schedules and scheme of works. They only participated in the data collection process by filling in the survey scale at time 1 and time 2.

Instrumentation

To collect data the study used a Likert scale survey questionnaire. The survey scale was developed by researchers from the literature. First, a literature review was done and the item pool was generated. Items were organised in such a way that the TPACK primary domains of technology, content, and pedagogy informed their interactions. This means the questionnaire ensured that some items from the primary domains were used to form items for TCK, PCK, TPK, and TPACK (Njiku et al., 2020a). The questionnaire was initially made of 82 items. The reliability analysis eliminated three items that were seen to negatively affect the reliability coefficients of the subscales. The resulting questionnaire had 79 items whereby the reliability analysis using Cronbach alpha indicated that the questionnaire was reliable, $\alpha = .93$. Specific domains were also reliable where the alpha values were: TK = .77, PK = .91, CK = .77, TCK = .89, PCK = .76, TPK = .79, TPACK = .87. The study further investigated construct validity using principal component factor analysis. However, considering the small sample size of 123 participants, it was not possible to run the factor analysis for the whole scale. Since the TPACK framework was used to guide the process of generating the items, and as such items were organised based on TPACK domains, each TPACK subscale was analysed separately (Schmidt, et al., 2009). The Monte Carlo PCA for Parallel Analysis was used to confirm the number of factors extracted using the factor analysis. Although the construct validity was approached quantitatively using the factor analysis, some decisions regarding specific items were made qualitatively. This analysis provided information that suggested the elimination of nine more items due to loading very weakly or not at all with the theoretical domains, leading to the extraction of more than one factor for the specific TPACK domains. The analysis information suggested the elimination of two items for the CK, three items from TPK, two items from PCK, and two items from TCK. However, the decision was made qualitatively based on what specific items were about and this retained one item from TCK and the two items from PCK. The final scale had a total of 73 items with the internal consistency of $\alpha = .97$. After this, the factor analysis was performed again on the TPACK domains and the final scale had 10 items for TK loading between .656 and .846 with $\alpha = .92$, 11 items for PK loading between .599 and .740 with $\alpha = .88$, nine items for CK loading between .582 and .864 with $\alpha = .86$, 14 for PCK loading between .508 to .799 with $\alpha = .81$, nine items for TPK loading between .679 and .905 with $\alpha = .93$, 10 items for TCK loading between .662 and .923 with $\alpha = .93$, and 10 items for TPCK loading between .781 and .898 with $\alpha = .96$. Therefore, based on these statistics, we considered the findings obtained from the data collected using this instrument as valid.

Data Analysis

Data was analysed through the help of version 20 of the Statistical Package for Social Science (SPSS) software. In addition to descriptive statistics, inferential statistics were used to detect whether differences in the data set were statistically significant. To respond to the first research question, the analysis of data was done using the paired sample t-test. This compared mathematics teachers' TPACK levels for pre-intervention (time 1) and post-intervention (time 2) data. All the three groups were involved in this comparison. To respond to the second research question, the split-plot analysis of variance was used. This analysis involved all the three groups as well and compared the difference in change of mathematics teachers between time I and time 2. In addition to the t-test and the split-plot analysis of variance, the effect size was determined using the eta squared (η^2) where .01=small; .06=modst; and .14=large (Cohen, 1988).

FINDINGS

The study was aimed at investigating the development of mathematics teachers' TPACK by their participation in professional development activities, particularly collaborative lesson design activities. Participants were

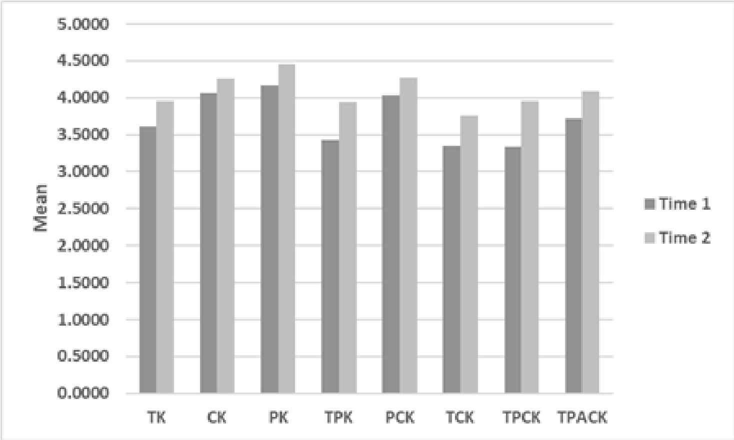

Figure 1. Group 1 mathematics teacher TPACK levers at time 1 and time 2

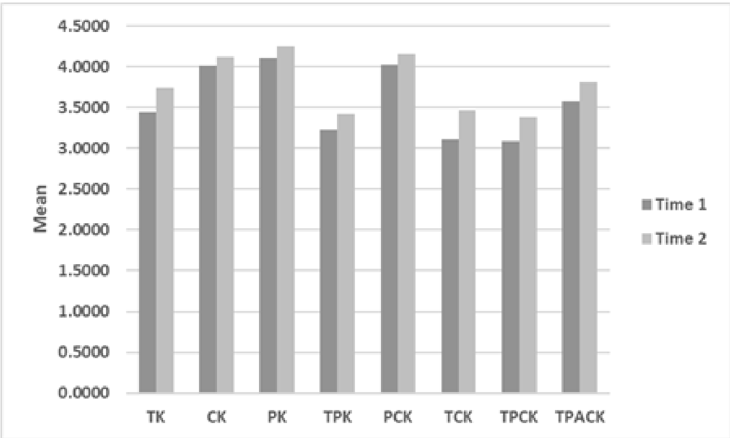

Figure 2. Group 2 mathematics teacher TPACK levers at time 1 and time 2

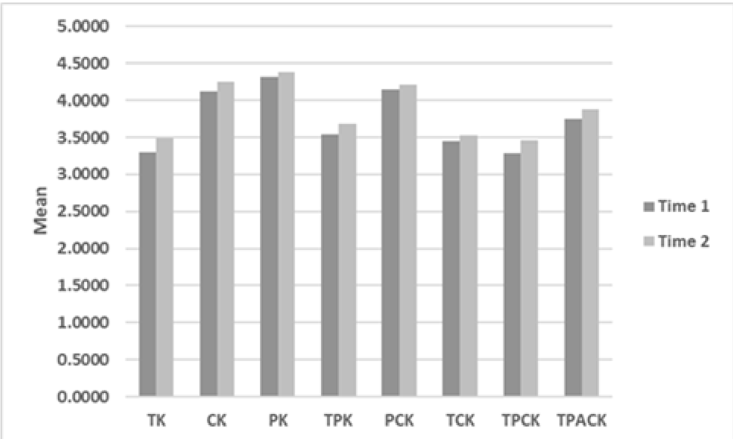

Figure 3. Group 3 mathematics teacher TPACK levers at time 1 and time 2

divided into three groups with different kinds of activities. All the groups were seen to improve in their TPACK between time 1 and time 2. Descriptive statistics indicated more improvement in group 1 followed by group 2. For example, when the comparison was made between the general TPACK mean score in the time 1 and time 2 survey data, the score for group 1 changed from 3.71 to 4.07 with an increase of 0.36 units, group 2 changed from 3.59 to 3.79 with an increase of 0.20 units and group 3 changed from 3.75 to 3.86 with an increase of 0.11 units. Information regarding the change in TPACK for specific domains for all the three groups is as shown in **Figures 1**-**3**.

Table 1. Change in group 1 mathematics teachers' TPACK between time 1 and time 2

	Time 1		Time 2					
Domain	*M*	*SD*	*M*	*SD*	*t*	*df*	*p*	η^2
TK	3.62	0.93	3.96	0.97	-3.573	39	.001	.25
CK	4.06	0.50	4.26	0.49	-2.701	40	.010	.15
PK	4.17	0.52	4.46	0.61	-3.343	40	.002	.22
TPK	3.42	0.77	3.94	0.68	-4.729	39	.000	.36
PCK	4.04	0.54	4.27	0.52	-3.768	39	.001	.27
TCK	3.34	0.83	3.74	0.81	-2.95	39	.005	.18
TPCK	3.34	0.93	3.95	0.70	-4.727	40	.000	.36
TPACK	3.71	0.59	4.07	0.55	-4.467	37	.000	.35

Table 2. Change in group 2 mathematics teachers' TPACK between time 1 and time 2

	Time 1		Time 2					
Domain	*M*	*SD*	*M*	*SD*	*t*	*df*	*p*	η^2
TK	3.44	0.85	3.73	0.70	-5.984	38	.000	.49
CK	4.01	0.45	4.12	0.36	-2.217	39	.033	.11
PK	4.11	0.38	4.25	0.37	-4.235	39	.000	.32
TPK	3.22	0.65	3.41	0.58	-3.33	39	.002	.22
PCK	4.04	0.33	4.14	0.31	-2.598	37	.013	.15
TCK	3.11	0.70	3.47	0.51	-5.429	39	.000	.43
TPCK	3.08	0.83	3.38	0.73	-5.485	39	.000	.44
TPACK	3.59	0.45	3.79	0.36	-5.732	36	.000	.48

Findings on Research Question 1

To provide more information in response to the first research question, the study investigated whether the change in TPACK between pre-intervention and post-intervention reached statistical significance. The paired sample t-test was used. In group 1, participants improved significantly at $p < .05$ their TPACK in all the domains and in general (see **Table 1**). Further analysis was done to determine the magnitude of the variances that contributed to this difference. The eta squared (η^2) was adopted as a measure for the effect size. In this group all the effect sizes were larger, that is being equal to or greater than 0.14.

When data from group 2 was used, it was found that participants improved their TPACK significantly at $P < .05$. This was somewhat similar to group 1. Unlike group 1 where all the calculated effect sizes were large, in group 2 the effect size for the CK domain was moderate. Nevertheless, all other domains had large effect sizes (see **Table 2**).

The data from the control group that was not intervened was also analysed for the purpose of comparison. The analysis indicated significant improvement in TPACK in five of the seven domains. The general TPACK improved significantly as well. From **Table 3** it can be observed that change in TPACK was not significant for the PCK and TCK domains. Similarly, the effect sizes for these domains were small. It can also be observed that the effect size for the general TPACK was moderate (see **Table 3**) unlike was the case for group 1 and group 2.

Table 3. Change in group 3 mathematics teachers' TPACK between time 1 and time 2

	Time 1		Time 2					
Domain	*M*	*SD*	*M*	*SD*	*t*	*df*	*p*	η^2
TK	3.30	0.99	3.48	0.95	-5.434	41	.000	.42
CK	4.12	0.39	4.25	0.37	-4.482	40	.000	.33
PK	4.31	0.42	4.38	0.39	-3.016	41	.004	.18
TPK	3.54	0.74	3.68	0.64	-3.734	41	.001	.25
PCK	4.15	0.37	4.19	0.34	-1.591	40	.119	.06
TCK	3.44	0.77	3.52	0.76	-1.688	41	.099	.06
TPCK	3.29	0.97	3.46	0.85	-4.09	41	.000	.29
TPACK	3.75	0.50	3.86	0.46	-7.725	39	.000	.60

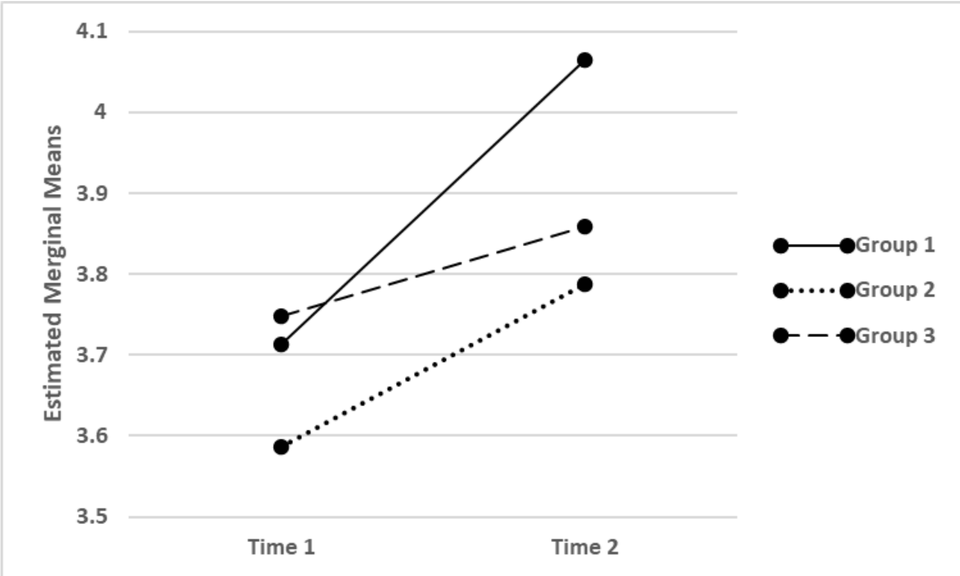

Figure 4. Effects of the interaction between time and treatment on mathematics teachers TPACK

Findings on Research Question 2

The second research question was about examining whether participation in professional development activities particularly collaborative lesson design activities influenced the development of mathematics teachers' TPACK. To address this research question, the split-plot analysis of variance was adopted. The analysis involved data from all the three groups and examined the magnitude of changes for each group between time 1 and time 2. In other words, the analysis compared whether the improvement between time 1 and time 2 was statistically the same for all the groups. Using the general TPACK scores, it was found that participants' scores changed significantly between time 1 and time 2, $F(1, 112) = 58.92$, $p < .01$, $\eta^2 = .32$, but the main effect of treatment was statistically non-significant, $F(2, 112) = 1.74$, $p = .18$, $\eta^2 = .00$. The effect of the interaction between time and treatment was statistically significant $F(2, 112) = 6.05$, $p < .01$, $\eta^2 = .07$. Since there was no significant difference based on treatment, the post hoc test could not provide any further information for the source of significant interaction between time and treatment. Therefore, a follow-up comparison had to be done using the SPSS syntax. This follow-up indicated that group 1 and group 2 were statistically different in TPACK levels at time 2 at $p = .04$ (see **Figure 4**). The detailed information from the split-plot analysis of variance is as summarised in **Table 4**.

Table 4. Effects of the time, treatments, and the interaction between time and treatment on mathematics teachers TPACK

	Time				Treatment				Interaction		
Domain	*df*	*F*	*p*	η^2	*df*	*F*	*p*	η^2	*F*	*p*	η^2
TK	1, 118	54.57	.00	.31	2, 118	2.12	.124	.00	1.50	.230	.02
CK	1, 119	21.61	.00	.15	2, 119	1.06	.349	.00	0.72	.487	.01
PK	1, 120	27.54	.00	.18	2, 120	1.77	.175	.00	4.24	.017	.05
TPK	1, 119	44.27	.00	.25	2, 119	3.65	.029	.00	7.68	.001	.09
PCK	1, 116	23.43	.00	.16	2, 116	0.50	.611	.00	4.98	.008	.07
TCK	1, 119	28.91	.00	.19	2, 119	1.51	.224	.00	3.93	.022	.05
TPCK	1, 120	54.45	.00	.29	2, 120	2.82	.064	.00	7.31	.001	.08
TPACK	1, 112	58.92	.00	.32	2, 112	1.74	.180	.00	6.05	.003	.07

DISCUSSION

The study investigated the development of mathematics teachers TPACK. This was done through a quasi-experiment that involved mathematics teachers in lesson design and implementation activities. One control group and two experimental groups were involved. All the groups were observed to improve their TPACK between the two points of time: before and after the intervention activities. These differences were statistically significant for all the groups. However, the effect sizes were larger for the first and second groups but not the control group. The study investigated further whether these differences would be attributed to the intervention activities. The split-plot analysis of variance found significant results indicating that the treatment influenced the change in TPACK scores of participants between the two points of time in favour of collaborative lesson design activities. Similar findings have been reported by Kafyulilo et al. (2013) who worked with 20 mathematics and science in-service teachers in two schools. They found an increase in TPACK particularly in technology-related domains. Focusing on professional development Alemdag et al. (2019) found that active participation in collaborative hands-on activities plays a crucial role in developing teachers TPACK. In initial teacher education, lesson design activities have also been found to develop pre-service teachers' TPCK (Kafyulilo et al., 2015; Kay, 2007; Lee & Kim, 2014).

This study found that teachers preferred using youtube videos and mobile phone apps. Probably this was due to easy access to these resources through their mobile devices. Also, the difference between Group I and Group 2 was based on the kind of activities in using these technologies. This suggests that it is not the technology that makes a difference but the way teachers are engaged with such technologies. Although the study was limited to these two technologies, researchers such as Harvey and Caro (2017) also worked with teachers who used online videos in the study. Harvey and Caro (2017) found that teachers who were guided in lesson design activities through the use of the TPACK framework improved their competences of teaching with technology than those who were not guided by the framework. Unlike the present study, other studies have involved teachers in the use of a number of technologies. For example, Lee and Kim (2014) involved participants in lesson design activities with a range of technologies including video clips, PowerPoint, web-based games, and online tests. This range of technologies maybe because of the ubiquitous access to technology in the United States of America where their study was done unlike the context of the present study where technology integration is at embryonic stages and challenges in resources are more likely (Njiku et al., 2020b) hence limiting participants of the present study to few technologies. Nevertheless, in line with Harvey and Caro (2017) and the findings of this study, it may be argued that the availability of resources is one thing and effective used for the development of TPACK, and hence transforming classroom practices is another. Also, efforts to address challenges regarding technology integration need to be approached contextually. It may be concluded that for effective development of teachers TPACK, working in groups as peers to design lessons may complement each other's strengths and help in overcoming challenges inherent in teachers' own professional competences.

CONCLUSION

This study investigated the development of mathematics teachers TPACK. Collaborative lesson design activities were central to this development. In line with existing literature, collaboration, lesson design activities, and consideration of relevant working contexts are considered important for the development of TPACK. Although all participating groups were seen to improve in their TPACK, evidence from the analysis indicates that the nature of the activities is paramount in enabling such development. In the era of rapid technological development and pressure on teachers to use technology in the facilitation of learning, they need to brush up on their knowledge and skills to cope up with such development. This calls for relevant professional development programmes that need to be not only engaging teachers actively but also within the context for authentic learning.

REFERENCES

Agyei, D. D., & Voogt, J. M. (2010). Exploring the potential of the will, skill, tool model in Ghana: Predicting prospective and practicing teachers' use of technology. *Computers and Education, 56*(1), 91-100. https://doi.org/10.1016/j.compedu.2010.08.017

Alemdag, E., Cevikbas, S. G., & Baran, E. (2019). The design, implementation and evaluation of a professional development programme to support teachers' technology integration in a public education centre. *Studies in Continuing Education*, 1-27. https://doi.org/10.1080/0158037X.2019.1566119

Chesley, G. M., & Jordan, J. (2012). What's missing from teacher prep. *Educational Leadership, 69*(8), 41-45. https://www.teacherscollegesj.edu/Content/pdfs/mentor/Whats%20Missing%20From%20Teachers%20Prep.pdf

Chukwuemeka, E. J., Nsofor, C. C., Falode, O. C., & Aniah, A. (2019). Assessing pre-service teachers' technological pedagogical content knowledge self-efficacy towards technology integration in colleges of education in south-west Nigeria. *Journal of Science, Technology, Mathematics and Education (JOSMED), 15*(3), 131-141. https://jostmed.futminna.edu.ng/images/JOSTMED/JOSTMED_153_SEPTEMBER_2019/12._Assessing_Pre-Service_Teachers_TPACK_Self-Efficacy_towards_Technology_Integration_in_COE_in_South-West_Nigeria.pdf

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). New York: Lawrence Erlbaum Associates.

Crompton, H. (2015). Pre-service teachers' developing technological pedagogical content knowledge (TPACK) and beliefs on the use of technology in the K-12 mathematics classroom: A review of the literature. In C. Angeli, & N. Valanides (Eds.), *Technological Pedagogical Content Knowledge, Exploring, Developing, and Assessing TPCK* (pp. 239-250). New York: Springer Science+Business Media. https://doi.org/10.1007/978-1-4899-8080-9_12

Daya, A., & Laher, S. (2019). Exploring the influence of educators' access to and attitudes towards educational technology on the use of educational technology in Johannesburg schools. *Africa Education Review, 17*(1), 159-180. https://doi.org/10.1080/18146627.2018.1490154

Drijvers, P. (2015). Digital technology in mathematics education: Why it works (or doesn't). In S. I. Switzerland, *Selected Regular Lectures from the 12th International Congress on Mathematical Education* (pp. 1-17). Switzerland: Springer International Publishing. https://doi.org/10.1007/978-3-319-17187-6_8

Farjon, D., Smits, A., & Voogt, J. (2019). Technology integration of pre-service teachers explained by attitudes and beliefs, competency, access, and experience. *Computers & Education, 130*, 81-93. https://doi.org/10.1016/j.compedu.2018.11.010

Getenet, S. T. (2017). Adapting technological pedagogical content knowledge framework to teach mathematics. *Education and Information Technologies, 22*(5), 2629-2644. https://doi.org/10.1007/s10639-016-9566-x

Handal, B., Campbell, C., Cavanagh, M., & Petocz, P. (2016). Characterising the perceived value of mathematics educational apps in preservice teachers. *Mathematics Education Research Journal, 28*(1), 199-221. https://doi.org/10.1007/s13394-015-0160-0

Handal, B., Campbell, C., Cavanagh, M., Petocz, P., & Kelly, N. (2013). Technological pedagogical content knowledge of secondary mathematics teachers. *Contemporary Issues in Technology and Teacher Education, 13*(1), 22-40. https://www.learntechlib.org/p/40713/

Harvey, D. M., & Caro, R. (2017). Building TPACK in preservice teachers through explicit course design. *TechTrends, 61*(2), 106-114. https://doi.org/10.1007/s11528-016-0120-x

Jaipal-Jamani, K., & Figg, C. (2015). The framework of TPACK-in-practice: Designing content-centric technology professional learning contexts to develop teacher knowledge of technology-enhanced teaching (TPACK). In C. Angeli, & N. Valanides (Eds.), *Technological Pedagogical Content Knowledge, Exploring, Developing, and Assessing TPCK* (pp. 137-163). New York: Springer Science+Business Media. https://doi.org/10.1007/978-1-4899-8080-9_7

Kafyulilo, A. C., Fisser, P., & Voogt, J. (2013). Supporting teachers' collaboration in design teams to develop technological pedagogical content knowledge: The case of science teachers in Tanzania. In R. McBride, & M. Searson (Ed.), *Proceeding of Society for Information Technology and Teacher Education International Conference, 2013*. (pp. 4692-4697). Chesapeake: VA: AACE. https://www.learntechlib.org/p/48865/

Kafyulilo, A., & Fisser, P. (2019). Developing TPACK in science and mathematics teacher education in Tanzania: a proof of concept study. In J. Pieters, J. Voogt, & N. P. Roblin (Eds.), *Collaborative curriculum design for sustainable innovation and teacher learning* (pp. 139-158). Switzerland: Springer Nature Open. https://doi.org/10.1007/978-3-030-20062-6_8

Kafyulilo, A., Fisser, P., Pieters, J., & Voogt, J. (2015). ICT use in science and mathematics teacher education in Tanzania: developing technological pedagogical content knowledge. *Australasian Journal of Educational Technology, 31*(4), 381-399. https://doi.org/10.14742/ajet.1240

Kay, R. (2007). A formative analysis of how preservice teachers learn to use technology. *Journal of Computer Assisted Learning, 23*(5), 366-383. https://doi.org/10.1111/j.1365-2729.2007.00222.x

Kearsley, G., & Shneiderman, B. (1998). Engagement theory: A framework for technology-based teaching and learning. *Educational Technology, 38*(5), 20-23. https://www.jstor.org/stable/44428478?seq=1#metadata_info_tab_contents

Kiekel, J., & Kirk, E. (2013). Evaluating apps to ensure learning outcomes. *Society for Information Technology & Teacher Education International Conference* (pp. 2171-2174). New Orleans: Association for the Advancement of Computing in Education (AACE). https://www.learntechlib.org/p/48427/

Kihoza, P., Zlotnikova, I., Bada, J., & Kalegele, K. (2016). Classroom ICT integration in Tanzania: Opportunities and challenges from the perspectives of TPACK and SAMR models. *International Journal of Education and Development using Information and Communication Technology, 12*(1), 107-128. https://www.learntechlib.org/p/173436/

Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education, 9*(1), 60-70. https://www.learntechlib.org/p/29544/

Koh, J. H. (2019). TPACK design scaffolds for supporting teacher pedagogical change. *Educational Technology Research and Development, 67*(3), 577-595. https://doi.org/10.1007/s11423-018-9627-5

Koh, J. H., & Chai, C. S. (2014). Teacher clusters and their perceptions of technological pedagogical content knowledge (TPACK) development through ICT lesson design. *Computers & Education, 70*, 222-232. https://doi.org/10.1016/j.compedu.2013.08.017

Lee, C. J., & Kim, C. (2014). An implementation study of a TPACK-based instructional design model in a technology integration course. *Educational Technology Research and Development, 62*(4), 437-460. https://doi.org/10.1007/s11423-014-9335-8

Maniraho, J. F., & Christiansen, I. M. (2015). How Rwandan grade 6 mathematics teachers teach - a first investigation. *Journal of Education and Practice, 6*(32), 148-158. https://eric.ed.gov/?id=EJ1083484

Mishra, P. (2019). Considering contextual knowledge: The TPACK diagram gets an upgrade. *Journal of Digital Learning in Teacher Education, 35*(2), 76-78. https://doi.org/10.1080/21532974.2019.1588611

Mouza, C. (2016). Developing and assessing TPACK among pre-service teachers. In M. C. Herring, M. J. Koehler, & P. Mishra, *Handbook of technological pedagogical content knowledge (TPACK) for educators* (pp. 169-189). New York: NY: Routledge. https://books.google.co.tz/books?hl=en&lr=&id=v0d-CwAAQBAJ&oi=fnd&pg=PA169&dq

Mtebe, J. S., & Raphael, C. (2018). Eliciting in-service teachers' technological pedagogical content knowledge for 21st-century skills in Tanzania. *Journal of Learning for Development, 5*(3), 263-279. https://jl4d.org/index.php/ejl4d/article/view/288

Mtebe, J. S., Dachi, H., & Raphael, C. (2011). Integrating ICT into teaching and learning at the University of Dar es Salaam. *Distance Education, 32*(2), 289-294. https://doi.org/10.1080/01587919.2011.584854

Mtebe, J. S., Kondoro, A., Kissaka, M. M., & Kibga, E. (2015). Using SMS mobile technology to assess the mastery of subject content knowledge of science and mathematics teachers of secondary schools in Tanzania. *International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering, 9*(11), 3498-3506. https://pdfs.semanticscholar.org/3733/ab49a9043f7cc470d514dfadef5710425659.pdf

Mtebe, J. S., Mbwilo, B., & Kissaka, M. M. (2016). Factors influencing teachers' use of multimedia enhanced content in secondary schools in Tanzania. *International Review of Research in Open and Distributed Learning, 17*(2), 65-84. https://doi.org/10.19173/irrodl.v17i2.2280

Nelson, M. J., Voithofer, R., & Cheng, S. L. (2019). Mediating factors that influence the technology integration practices of teacher educators. *Computers & Education, 128*, 330-344. https://doi.org/10.1016/j.compedu.2018.09.023

Niess, M. L. (2015). Transforming teachers' knowledge: Learning trajectories for advancing teacher education for teaching with technology. In C. Angeli, & N. Valanides (Eds.), *Technological pedagogical content knowledge: exploring, developing, and assessing TPCK* (pp. 19-37). New York: Springer Science+Business Media. https://doi.org/10.1007/978-1-4899-8080-9_2

Njiku, J., Mutarutinya, V., & Maniraho, J. F. (2020a). Developing technological pedagogical content knowledge survey items: A review of literature. *Journal of Digital Learning in Teacher Education, 36*(3), 150-165. https://doi.org/10.1080/21532974.2020.1724840

Njiku, J., Mutarutinya, V., & Maniraho, J. F. (2020b). Mathematics teachers' technology integration self-efficacy and technology use. *International Conference to Review Research in Science, Technology, and mathematics Education* (pp. 283-289). Mumbai: Homi Bhabha Centre for Science Education. https://episteme8.hbcse.tifr.res.in/proceedings/

Ocak, C., & Baran, E. (2019). Observing the indicators of technological pedagogical content knowledge in science classrooms: Video-based research. *Journal of Research on Technology in Education, 51*(1), 43-62. https://doi.org/10.1080/15391523.2018.1550627

Roussinos, D., & Jimoyiannis, A. (2019). Examining primary education teachers' perceptions of TPACK and the related educational context factors. *Journal of Research on Technology in Education, 51*(4), 377-397. https://doi.org/10.1080/15391523.2019.1666323

Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological pedagogical content knowledge (TPACK): The development and validation of an assessment instrument for preservice teachers. *Journal of Research on Technology in Education, 42*(2), 123-149. https://doi.org/10.1080/15391523.2009.10782544

Scriven, M. (2014). The logic of causal investigations. In A. D. Reid, P. E. Hart, & M. A. Peters (Eds.), *A companion to research in education* (pp. 163-172). New York: Springer Science and Business Media Dordrecht. https://doi.org/10.1007/978-94-007-6809-3_21

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14. https://doi.org/10.3102/0013189X015002004

Sife, A. S., Kiondo, E., & Lyimo-Macha, J. G. (2010). Contribution of mobile phones to rural livelihoods a poverty reduction in Morogoro region, Tanzania. *The Electronic Journal on Information Systems in Developing Countries, 42*(3), 1-15. https://doi.org/10.1002/j.1681-4835.2010.tb00299.x

Uslu, N. A., & Usluel, Y. K. (2019). Predicting technology integration based on a conceptual framework for ICT use in education. *Technology, Pedagogy and Education, 28*(5), 517-531. https://doi.org/10.1080/1475939X.2019.1668293

Weber, N. D., & Waxman, H. C. (2015). Changes in first-year teachers' self-efficacy and confidence for integrating technology into classroom instruction. *SITE 2015*, 3493-3499. https://www.learntechlib.org/p/150485/

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