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Pedagogical content knowledge: bridging math teachers' technology knowledge and perceived usefulness

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ABSTRACT

The responsibility of mathematics teachers to accept technology into their instructional delivery has been a must know knowledge as professional development of Ghanaian teachers is ongoing to welcome the new standard-based curriculum by the end of 2024 at the senior high schools. This study investigated how conventional pedagogical content knowledge (PCK) influences the adoption and perceived utility of technology among mathematics teachers. Conducted with 979 mathematics teachers purposefully sampled from senior high schools in the Ashanti region of Ghana, the study employed structural equation modeling (SEM) to analyze the relationship between technology knowledge (TK), PCK, and perceived technology usefulness (PTU). The findings indicated a direct relationship between TK and PTU, with no significant mediation effect of PCK observed. Furthermore, professional experience (PE) did not moderate this relationship. However, TK was found to significantly influence PCK, thereby impacting the quality of instruction provided by teachers. Additionally, PCK was identified as a significant predictor of PTU. The study implications lies in its anticipation that Ghanaian mathematics teachers' TK is perceived to enable them to leverage digital tools and resources effectively to connect it to their PCK, ultimately to lead to more engaging, effective, and impactful mathematics instruction delivery. This will foster meaningful learning experiences aligned with curriculum goals and learners needs.

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1. INTRODUCTION

Technology's rise has significantly impacted education, emphasizing its integration into curriculum [1], [2], yet it remains underutilized despite its potential to improve mathematics instruction [3], [4]. Meanwhile, the 21st century demands a must-know technology proficiency from teachers, requiring them to be skilled in both technology and teaching methods to help learners to be creative, critical thinkers, and communicate effectively in collaborative approaches while solving practical world problems [5]–[8]. While teachers play a key role in integrating technology, accepting it does not guarantee its use in lessons [5], [9]. To address this, stakeholders in Ghana, like National Teaching Council (NTC) and National Council for Curriculum and Assessment (NaCCA), are collaborating to integrate technology into education through the curriculum and professional learning community (PLC) initiatives [10]–[12]. In the previous study by McIlveen *et al*. [13], doing so encourages teachers to remain professionally sustainable.

Teachers are under pressure to embrace technology even though they have liberty over its usage, Ghanaian teachers' integration of technology with traditional pedagogical content knowledge (PCK) is essential for effective teaching [14], [15]. Teachers' acceptance and ability to integrate technology knowledge (TK) into mathematics teaching and learning were assessed using PCK from the technological pedagogical and content knowledge (TPACK) and technological acceptance model (TAM) frameworks. Numerous researchers [16]–[19] have attempted to investigate how technology integration affects teachers' acceptance of it, but they have not taken into account the way that conventional PCK mediates the acceptance and perceived use of technology. Nonetheless, taking into account the moderating effect of teachers' professional experience (PE) between their TK and their perceived technology usefulness (PTU) has received little or no attention in the Ghanaian mathematics educational research field. The study aimed to fill a gap in the literature by investigating the following hypotheses: i) there is no significant effect of teachers' TK on their PCK (H_{01}); ii) there is no significant effect of teachers' PCK on their PTU (H_{02}); iii) there is no significant effect of teachers' TK on their PTU (H_{03}); iv) there is no significant mediation role of PCK between teachers' TK and PTU (H_{04}); and v) there is no significant moderation role of PE between teachers' TK and PTU (H_{05}).

The study by Lee *et al.* [20] are one of the view that some experienced teachers may be open to integrating technology into their instructional practices after recognizing its potential to enhance learner learning outcomes, regardless of their years of experience. Sims and Fletcher-Wood [21] also indicated that experienced teachers who value professional development and lifelong learning may actively seek out opportunities to enhance their TK and skills. Chai *et al.* [22] highlight the challenge of integrating knowledge in pedagogy, subject matter, and technology. According to Harit [8], Shulman advocates for the concept of PCK in education, teachers must understand curriculum, pedagogy, material, and their interactions. Several studies [8], [22]–[27] have all explored the role of PCK in education. PCK is a personal quality that connects content knowledge to pedagogical knowledge; influencing pedagogical rational thought [26]. It involves understanding, justifying, preparing, and implementing teaching strategies to improve student outcomes. Some scholars contend that there is no real difference between PCK and content knowledge, content knowledge may be altered for instructional reasons [24], [28], [29]. In an effective analytic course, study by Delgado-Rebolledo and Zakaryan [27] investigates the link between a lecturer's PCK and mathematical understanding. The study makes use of the math teacher's specialized knowledge approach, which combines PCK with specialized expertise for math teachers. Their study shows that a teacher's understanding of mathematical concepts affects their knowledge of instructional strategies, metaphors, and analogies.

PCK and technological resources are complex and multifaceted, reflecting the way evolution has revolved around cycles of growth and accumulation [30]. O'Connor *et al.* [31] explored the use of digital technology and pedagogy before and after the 2020/21 Vietnam lockdown. The study reveals that teachers' perceptions and experiences during this period were diverse, with some finding new pedagogical techniques challenging, while others enjoyed the opportunity to experiment with different teaching methods. Previous studies [32], [33] contend that by taking a look at the TPACK constructs teachers have, it is possible to integrate technology and PCK in the classroom. However, Spangenberg and Freitas [34] highlights how shifts in education and society have affected the selection and use of PCK and related technologies. Meanwhile, Ching and Robert [35] belief that no amount of technology advancement can undermine the importance of PCK. Notwithstanding, high-stage TPACK teachers will ease their learners' steps and actions to a collaborative approach as they explore technology in the mathematics classroom [32]. Lee *et al.* [20] discovered common threads in publications that addressed TPACK, teacher preparation, technological skills, and pedagogy while also focusing on PCK, teacher knowledge, and teacher education. Rakes *et al.* [36] also assert that the absence of correlation in their findings is evidence that the technology in TPACK is an essential and distinct sort of knowledge that does not automatically grow alongside PCK.

Hong and Yu [37] indicated that the TAM paradigm postulates a connection between outside factors and both perceived usefulness and perceived usability. By using Bandura's concept of outcome judgment, Lewis [38] defines perceived utility as a person's assessment of the degree to which utilizing a technology improves performance. According to Yang *et al.* [19], teachers perceived utility of technology was significantly influenced by their degree of TPACK. In particular, e-Schoolbag approval was more strongly connected with the TK component than with the PCK components.

2. METHOD

To research the above-mentioned gap, a positivist paradigm emphasizing empirical investigation was crucial. The study employed a correlational design using a quantitative approach to demonstrate teachers' acceptance and perceived usefulness of technology through their PCK in senior high school math instruction in Ghana.

2.1. Sample and population

A PLC workshop has been on going at government senior high schools nationwide since June 2023, making mathematics teachers attending these sessions' ideal candidates for the study. As Turner [39] noted, a sample is a fraction of the whole, selected to participate in the research project. The study used Turner [39] method to select a representative sample of 1,100 mathematics teachers in the Ashanti Region of Ghana, known for its diverse teacher community and high concentration of senior high school mathematics teachers.

2.2. Questionnaire validity and reliability

The study adhered to the code of ethical practice and declared its commitment to ethical considerations by seeking permission from the university ethics select committee before administering the questionnaire to the respondents. The structured questionnaire underwent pilot testing in four Kumasi municipalities to ensure clarity and consistency. The September 2023 pilot survey assessed the dependability of the data based on multiple researchers' adaptations [11], [14], [38]. The researchers used a five-point Likert scale to score questions in the study, reworded unclear wording during the piloting. The piloted data showed Cronbach's alpha TK (0.710), PCK (.765), and PTU (0.864) on 264 sample sizes, resulting in an overall alpha of 0.808.

2.3. Data collection procedure

After the reliability and validity test, the survey was conducted using both hard and online questionnaire to address geographical participant spread, ensuring accurate collection of respondents' demographics, TK, PCK, and PTU data. Data analysis involved accessing and coding survey data using Microsoft Office Excel 2019 and employing a three-step approach to structural equation modeling (SEM), including exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and SEM using statistical package for the social sciences (SPSS) and analysis of moment structures (AMOS) software's. However, only 979 of the questionnaires were deemed suitable for data analysis after data collection, yielding an extremely high response rate of 89.0% [(979/1,100)100], which qualified the study for acceptance.

3. DESCRIPTIVE ANALYSIS

Of the total respondents, 83.6% were males and 16.4% were females. The age distribution, from highest to lowest, is 35-44 years (41.3%), 25–34 years (40.3%), 45–54 years (11.1%), below 25 years (5.9%), and above 54 years (1.2%). Among the sample, 8.3% are not professional teachers, while over 91.7% are. Most respondents hold a first degree (76.9%), with only 23.1% holding a second degree. Their teaching experience ranges from 6 to 15 years (42.1%), with 25-35 years (1.8%) constituting the minority.

The EFA, guided by Hair *et al*. [40], produced a Kaiser-Meyer-Olkin measure of sampling adequacy of 0.828, indicating 82.8% adequacy of the observable variables loading correctly onto the latent variables. Bartlett's test of sphericity yielded a significant p-value of 0.000, indicating a substantial correlation suitable for component analysis. The first three components, each explaining more than 5% of the variance, collectively accounted for 64.670% of the total variance, highlighting their significance in explaining data variability.

To make the CFA model better, components with factor loadings less than 0.50 were usually eliminated. Following the CFA procedure, the observed variables maintain all five items for each of the latent variables under study except TK which was reduced by one, as shown in Figure 1. Achieving internal consistency through Cronbach's alpha (CA) entailed obtaining a score of at least 0.7 [41]. As indicated in Table 1, TK exhibited a CA of 0.814, PCK showed a CA of 0.842, and PTU demonstrated a CA of 0.903.

The model fit indices indicated a significance level in all the major fitness values. The goodness of fit index (GFI=0.976), normed fit index (NFI=0.973), increment fit index (IFI=0.984), and Tukey-Lewis index (TLI=0.978), were all greater than 0.9, indicating that the data of the three-factor model is valid and remarkably compatible, as cited in Oppong-Gyebi and Boateng [42]. The adjusted goodness of fit index (AGFI=0.963) was greater than the expected 0.80 as declared by Hair *et al*. [40]. Per the recommendations of Marsh *et al*. [43] and Meyers *et al*. [44], as discussed by Afthanorhan *et al*. [45], which expect all the latent variables to have a deviation of the hypothesized model from a better match, the root means square residual (RMSEA) also showed a good match of 0.040 less than 0.08, confirming the legitimacy and acceptability of the essential factors (Table 1).

Before estimating the primary path, assessing the validity and reliability of the dataset and measurement items was essential, as customary in empirical studies. CFA was conducted using AMOS (v.23) software. The results of CFA, presented in Table 1 and Figure 1, were evaluated using composite reliability (CR) and average variance extracted (AVE) to ensure convergent validity. According to Afthanorhan *et al.* [45], a minimum AVE score of 0.5 and a minimum CR score of 0.7 are necessary for convergent validity. The lowest AVE value, observed for PCK, was 0.528, while the lowest CR value, noted for TK, was 0.835.

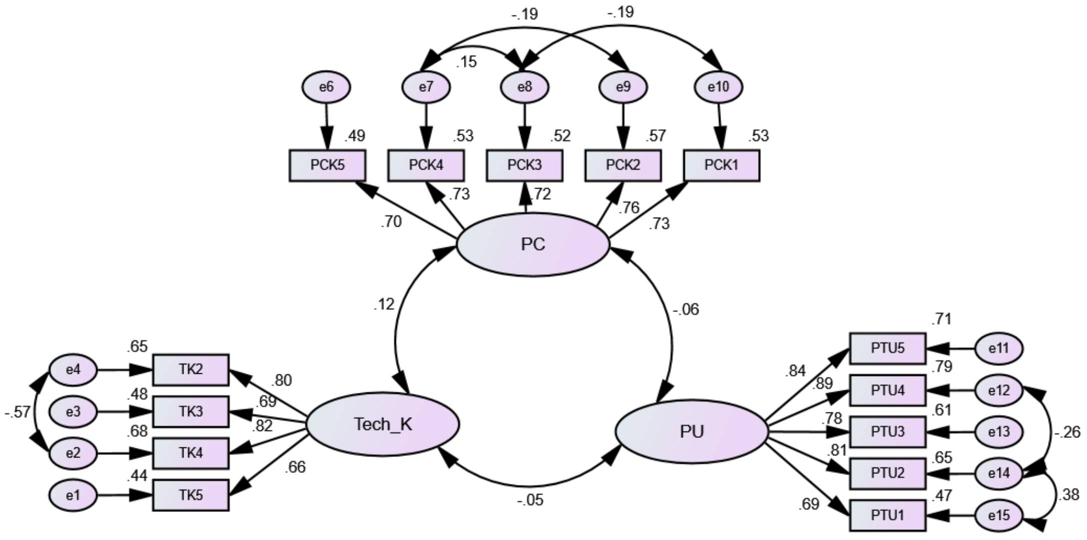

Figure 1. CFA

Table 1. Convergent validity and CR

Items	FL	CR	AVE	MSV	α	Items	FL	CR	AVE	MSV	α
TK		0.835	0.561	0.015	0.814	PCK		0.848	0.528	0.015	0.842
TK2	0.804					PCK1	0.728				
TK3	0.963					PCK2	0.757				
TK4	0.823					PCK3	0.718				
TK5	0.664					PCK4	0.728				
						PCK5	0.700				
PTU		0.901	0.647	0.003	0.903	Model fit indices					
PTU1	0.688					CMIN=463.519				RMR=0.063	
PTU2	0.809					DF=157.000				AGFI=0.963	
PTU3	0.781					CMIN/DF=2.952				NFI=0.973	
PTU4	0.889									IFI=0.984	
PTU5	0.841									TLI=0.978	
										RMSEA=0.040	

FL=factor loadings, α=Cronbach's alpha, SE=self-efficacy, PU=perceived usefulness, TUI=technology usage intention, MID=STEM-mathematics instructional delivery.

4. RESULTS

To examine each of the hypotheses, the SEM was used for the analysis using SPSS (add-in PROCESS_v4.2_beta). However, AMOS (v24) software was used to draw and evaluate various hypothesized routes, with a diagrammatic representation of the structural model, as presented in Figure 2. The study then applied the bias-corrected (BC) percentile bootstrapping approach to 5,000 bootstrap samples with a 95% confidence level, resulting in a structural model that satisfied all fit indicators suggested by Hair *et al.* [40], and Goretzko *et al.* [41], just like the CFA did.

For the hypothesized paths, it was identified that teachers' TK had a statistically significant effect on their PCK (a_1=0.145; $p<0.05$). Hypothesis H_{01}: "there is no significant effect of teachers' TK on their PCK", was therefore rejected by this study. Teachers' PCK, on the other hand, had a significant effect on their PTU (a_2=-0.104; p=0.023). Suggesting that, as teachers used PCK, their PTU is likely to decline by about 10.4%, and vice versa. Hypothesis H_{02}: "there is no significant effect of teachers' PCK on their PTU", was therefore rejected by this study. Teachers' TK had a statistically significant effect on their PTU (b_3=-0.115; p=0.012). Hypothesis H_{03}: "there is no significant effect of teachers' TK on their PTU", failed to support the null hypothesis, as shown in Table 2.

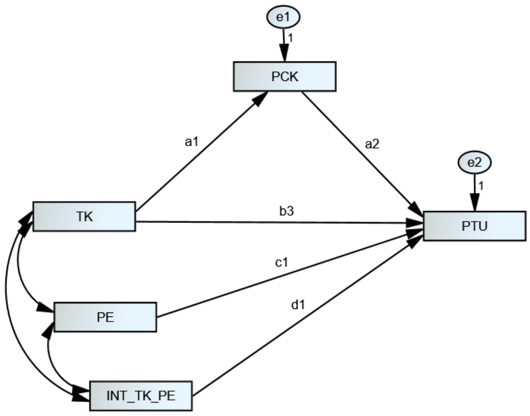

Figure 2. Structural path

Table 2. Summary of the hypothetical analysis results

Hypotheses	Antecedent	Path	Coeff.	SE	C.R	P	Remark
			Y (PCK)				
H_{01}	TK (x)	a_1	0.145	0.032	4.53	0.000	Significant
			Y (PTU)				
H_{02}	PCK (x)	a_2	-0.104	0.046	-2.26	0.023	Significant
H_{03}	TK (x)	b_3	-0.115	0.046	-2.50	0.012	Significant

Note. Dependent variable (Y), predictor (X), C.R: critical ration; SE: standard error.

Finally, the mediating effect of teachers' PCK in the relationship between their TK and PTU and their PE interacting between TK and PTU was ascertained. Firstly, the effect of teachers' TK on their PTU was ascertained and found to be significantly positive (a_1=0.145; $p<0.05$), as seen in Table 3 That is, teachers knowledgeable in technological skills are likely to have a greater positive knowledge of mathematics pedagogy and content used in instructional delivery, by a magnitude of 14.5%, and vice versa.

The effect of teachers' TK on their PTU has also been identified as significantly positive. However, PE (c_1=-0.009; $p>0.05$) and the interaction of PE and TK (d_1=0.028; $p>0.05$), respectively, on PTU failed to be significant. This indicates that the moderating role of PE has little or no significant impact on the model. The coefficient of the indirect effect was -0.013, which was statistically insignificant (because zero (0) can be found between the lower and upper limits), while the direct effect was statistically significant. Hypothesis H_{04}: "there is no significant mediation role of PCK between teachers' TK and PTU" showed no mediation role but rather revealed a direct relationship among the constructs. Based on the statistically insignificant role of the moderator, hypothesis H_{05}: "there is no significant moderation role of PE between teachers' TK and PTU" failed to be rejected.

Table 3. Mediating role of PCK between TK and PTU

Antecedent	Mediator (PCK)					Dependent (PTU)				
	Path	Coeff.	SE	CR	P	Path	Coeff	SE	CR	P
H_{04} and H_{05}		M (SE)					Y(PTU)			
Constant	β_{PCK}	2.619	0.029	90.62	0.000	β_{PTU}	3.065	0.128	23.95	0.000
TK (x)	a_1	0.145	0.032	4.53	0.000	b_3	-0.102	0.046	-2.22	0.027
PCK (M)						a_2	-0.089	0.046	-1.93	0.055
PE						c_1	-0.009	0.041	-0.22	0.837
TK(PE)						d_1	0.028	0.046	0.61	0.546
Antecedent	Path	Effect	SE		P		LL	UL		Remark
Indirect	$a_1.b_1$	-0.013	0.007				-0.029	0.000		Direct relationship
Direct	c_1	-0.102	0.046		0.027		-0.193	-0.011		

Note: Dependent variable (PTU), Predictor (TK), Mediator (PCK), Moderator (PE), C.R=Critical ration; LL=Lower limit; UL=Upper limit

5. DISCUSSION

The study revealed a statistically significant effect of teachers' TK on their PCK. It indicates that the recent collaborative effort by the Ghana's education service and other stakeholders in providing technological tools and organize professional workshops are empowering mathematics teachers to include technology into their instructional delivery [10], [12]. This is in support of Spangenberg and Freitas [34] findings that see educational advancement and society having a positive impact on the selection and use of technology in related PCK to impact quality instruction. In supporting the findings by Yanuarto *et al*. [32], taking a look at teachers' knowledge in technology, it is possible to for them to possess a strong understanding of how to effectively integrate technology into their classrooms to enhance their PCK delivery. Contrary to previous beliefs as indicated by Ching and Robert [35] that irrespective of how technology advances, PCK will be dominant over TK. Thus, the result is consistent with several prior studies [17], [19] that indicated a significant impact of teachers' knowledge and choice of technological skills on their PCK.

It is interesting to note from the findings that mathematics teachers' PCK has a significant impact on how they perceived the usefulness of technology, shaping their attitudes and beliefs about the value of technology in the classroom. In support of the finding, Lee *et al*. [20] see a well-prepared teacher abreast with PCK always have the desire to integrate technology into their instructional delivery. As indicated by previous studies [28], [29], developing the PCK of in-service mathematics teachers empowers them to use any form of technology to enhance their classroom instructional delivery. Supporting the study result, teachers' deep understanding of PCK enables them to identify how technology can enhance their teaching practices and support student learning outcomes [30], [35]–[37]. Lewis [38] also shares the view of this study's finding where TK shows significant effect on PTU that teachers who feel confident in their ability to use technology are more likely to perceive it as a valuable tool for enhancing teaching and learning experiences, rather than a source of frustration or inconvenience.

PE does not moderate the relationship between teachers' TK and their PTU. The finding goes contrary to other studies [20], [21] that expressed how teachers experience ignite their zest to use technology in their classrooms. Instead, individual perceptions and attitudes toward technology integration play a more significant role. While experienced teachers may have more teaching experience, their perceptions of technology usefulness may still vary depending on factors such as exposure to technology integration initiatives and personal attitudes toward technology adoption. The study found that PCK does not serve as a crucial mediator between teachers' TK and their PTU. Contrary to Spangenberg and Freitas [34], who identified effective use of technology in teachers' PCK and pedagogical beliefs about technology as some obstacles in mathematics classrooms.

Based on the findings of the study, it is anticipated that Ghanaian mathematics teachers' TK is perceived to enable them to leverage digital tools and resources effectively to enhance their PCK, ultimately leading to more engaging, effective, and impactful mathematics instruction delivery. In the same instance, mathematics teachers' PCK does not profoundly influences their TK and subsequently impacts their PTU to use it in their classrooms, as revealed by several studies [31], [34], [35]. Moreover, as emphasized by Lee *et al*. [20], PCK continues to be a guidance for teachers in choosing relevant technology resources and tools that complement learners' needs and instructional objectives. It would be pointless to use technology without pedagogy and content expertise. Hence, technology cannot be in isolation without integrating through PCK to enhance instructional delivery quality. Analyzing these considerations leads the researchers to the conclusion that selecting TK independently, without enlisting PCK to play a mediating role in future technology integration, could negatively affect the quality of effective 21st century instruction delivery in Ghanaian senior high schools. As indicated by Yeh *et al.* [33], technology mediating through PCK empowers teachers to design and implement technology-enhanced learning experiences. The way forward to integrating technology through mathematics teachers' PCK could create a meaningful learning opportunity that might enhance their PTU as stressed by Bayram-Jacobs *et al*. [26].

The mathematics teachers' reluctance to respond to the questionnaire prompted their heads of department to intervene. Despite many teachers being occupied with marking the recent West Africa Secondary School Certificate Examination in core mathematics, the heads of departments consistently reminded them to complete the questionnaire.

6. CONCLUSION

The study investigated how PCK mediates the acceptance and perceived use of technology among 979 mathematics teachers in senior high schools in the Ashanti Region of Ghana. After using SEM to estimate the model, the results show no mediating role of PCK but a direct relationship between TK, PCK, and perceived usefulness in mathematics education. PE did not moderate this relationship. However, TK significantly influences PCK, which in turn impacts the quality of instruction provided. The study also reveals that teachers' TK significantly influences their perceived usefulness, influencing their attitudes and beliefs about the value and effectiveness of technology in the classroom. The findings also highlighted the importance of PCK in promoting effective technology use in education.

The value of this study embeds in how Ghanaian mathematics teachers' PCK has revealed not to play a crucial role in linking their TK with PTU. To prevent this constraint, education stakeholders should foster positive attitudes towards technology adoption and encourage its meaningful integration into mathematics education in Ghana. Leveraging technology can enhance personalized instruction, collaborative learning, and real-world applications of mathematical concepts, thereby improving teaching effectiveness. The study recommends that teachers prioritize PCK to help teachers' select suitable technology for lesson planning, instructional delivery, and assessment, creating meaningful learning opportunities aligned with curriculum goals and enhancing their PTU.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest in the publication of this article.

ETHICAL APPROVAL

This study was done as part of the academic requirement for Ph.D. candidates and has been approved by the Department of Mathematics Education, and the ethical committee of AAMUSTED.

DATA AVAILABILITY

The data for this study is not publicly available. However, it can be proved upon request from the corresponding author [EOG].

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