Teachers' planning and teaching decisions: A TPACK in context perspective

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We conducted this observational study to understand the application of technological pedagogical and content knowledge (TPACK) by eight educators from a university in Australia when making planning and teaching decisions. We observed them in both their lesson planning and delivery using think-aloud and recorded lesson categorisation. Teacher time was found to be overall 60% devoted to these expanded knowledge bases compared to 40% in the TPACK framework. Large differences were observed between planning versus delivery in terms of the usage of these TPACK in context knowledge bases with around 75% of planning being in the expanded categories versus 40% in delivery. Dynamic processes to set goals, select appropriate knowledge bases and then apply them were observed as a frequent teaching pattern with 19 knowledge bases and combinations. TPACK can be systematically expanded and teaching with technology may be better understood using a holistic and non-prescriptive observational approach to make sense of teaching practices prior to categorising them. Future research could benefit from exploring the use and interaction of these TPACK in context knowledge bases along with their distinctive characteristics.

Implications for practice or policy:

- Teacher education programmes could redefine their technology in teaching curriculum to include a broader range of knowledge bases beyond content, pedagogy and technology or their combinations.
- Professional development programmes for in-service teachers could address teaching practices holistically so that technology use is not separated from overall lesson development skillsets.
- Policymakers could provide additional funding and resources for professional development opportunities for teachers and use a targeted approach with common technology provisions.

Keywords: technological pedagogical and content knowledge (TPACK), knowledge bases, tertiary education, observational study, think aloud

Introduction

Mishra and Koehler's (2006) technological pedagogical and content knowledge (TPACK) theoretical framework is common in many teacher education programmes for practically addressing technology use in teaching. The framework helps to equip teachers with an understanding of how to embed digital technology in their teaching (Lee et al., 2022). It is a keystone framework for providing teachers with a practical toolset to understand the application of technology in teaching. TPACK has received significant attention from researchers due to its emphasis on the integration between content, pedagogy and technology, forming four combined knowledge bases: pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK) and TPACK. Mishra and Koehler (2006, p. 1025) documented the effectiveness of their model as a distinct framework to categorise teachers' knowledge and provide a window into teachers' practices emphasising connections, interactions, affordances and constraints between and among content, pedagogy and technology. While initially only theoretically descriptive of teacher practices, TPACK has become practice based with direct application by teachers, and this had led to gaps in clarity; our study sought to address these gaps.

This research focused on an observational investigation to evaluate the extent to which the TPACK framework can adequately describe effective teaching practices demonstrated by experienced educators.

The research questions to investigate the application of TPACK in teachers' planning and teaching were:

1. What additional meaningful knowledge bases do teachers often draw upon during lesson planning and classroom instruction that are not accounted for in the traditional TPACK framework?
2. What combinations of those knowledge bases do teachers use on a frequent basis when planning and teaching using technology in different contexts?
3. What makes teachers combine various knowledge bases during lesson planning and classroom instruction?

Literature review

Theoretical foundation of TPACK

The TPACK framework, by Mishra and Koehler (2006), builds upon Shulman's (1986) concept of PCK. Shulman (1987) proposed seven teacher knowledge bases: content knowledge, general pedagogical knowledge, curriculum knowledge, PCK, knowledge of learners, knowledge of educational contexts and knowledge of educational ends. Later studies in this area concentrated on PCK, while other knowledge bases were grouped under a vaguely defined category of contextual factors (Cochran et al., 1993; Grossman, 1990). Among these, the integration of technology in teaching emerged as an area of particular interest, driven by the growing potential and accessibility of technological tools (Harris et al., 2017; Markauskaite et al., 2011).

Mishra and Koehler's (2006) TPACK framework extended Shulman's (1987) work by incorporating technology into the construct, emphasising the dynamic interplay among seven interrelated domains: technology, pedagogy, content, TPK, TCK, PCK and TPACK. In 2009, the model was revised to include a dotted outer circle labelled "contexts", representing the influence of teaching environments (Koehler & Mishra, 2009). Later, Mishra (2019) proposed relabelling this as "conteXual knowledge" (XK) for semantic consistency, arguing that every enclosed space in the diagram should represent a form of teacher knowledge. More recently, Petko et al. (2025) refined the model by distinguishing between XK and contexts: XK refers to teachers' knowledge of their specific teaching environments, while contexts represent the broader environment in which teaching and learning occur.

TPACK extensions and variations

Since its inception, TPACK has been adapted and extended in many ways that either address particular technologies or disciplines, including TPCK-Web (Lee & Tsai, 2010), technological pedagogical science knowledge (Jimoyiannis, 2010), TPACK in geography (Doering et al., 2014), science, technology, engineering and mathematics-TPACK (Chai et al., 2020), or make contextual influences more explicit, for example, information and communications technology-TPCK (Angeli & Valanides, 2009) and ecological-TPACK (Yang & Dong, 2024). Some studies have also conceptualised TPACK as shared knowledge distributed across people and artefacts, arguing that the knowledge required for technology integration can be shared among teachers, students and other supports rather than residing only in the teacher's head (Di Blas et al., 2014; Di Blas & Polini, 2016; Nore et al., 2010). While these extensions respond to legitimate disciplinary and contextual needs in specific contexts, the proliferation of variants can dilute the overall conceptual coherence when describing similar or overlapping constructs. Given the number and overlap among variants, this paper did not attempt an exhaustive review of TPACK extensions, but sought to consolidate important and frequently observed knowledge base definitions.

Empirical studies on TPACK

Empirical research has shown the knowledge bases teachers draw upon are often blurry and imbalanced. In many cases, the knowledge bases are not clearly distinguished, and some knowledge bases or combinations of them appear more prominently than others in empirical findings (Archambault & Barnett, 2010; Archambault & Crippen, 2009; Chai et al., 2010; Chai et al., 2011; Koh et al., 2010; Scherer et al., 2017). Studies have indicated teachers' integration of TPACK knowledge bases is dynamic and context dependent. However, much of the empirical evidence has come from pre-service teachers, and comparisons suggest that in-service teachers may apply and integrate these knowledge bases in different ways (Tschönhens et al., 2024).

Chai et al. (2010) conducted a longitudinal study with 889 Singaporean pre-service secondary teachers. Using regression analysis on adapted versions of Schmidt et al.'s (2009) TPACK survey, the study found that TK, PK and CK were all significant predictors of pre-service teachers' TPACK, with PK having the largest impact. A similar study (Chai et al., 2011) was conducted with 834 pre-service primary teachers, in which five statistically distinct constructs – TK, PK, CK, TPK and TPACK – were identified through exploratory factor analysis. Both studies suggested that TPACK development may follow a staged or layered process, evolving through experience and targeted instruction.

Koh et al. (2010) examined the construct validity of TPACK using Schmidt et al.'s (2009) instrument with 1,185 pre-service teachers in Singapore. An exploratory factor analysis identified five distinct constructs: TK, CK, knowledge of pedagogy, knowledge of teaching with technology and knowledge from critical reflection. The participants in Koh et al.'s study did not make conceptual distinctions between TPACK constructs such as TCK and TPK.

Archambault and Barnett (2010) extended the inquiry of the validity of TPACK's construct by surveying 596 online teachers in the United States of America. The study found that only TK could be clearly separated from other knowledge bases, while TCK, TPK and TPACK showed overlapping boundaries. These findings highlight the persistent challenge of empirically validating the TPACK domains. The survey results were analysed in a separate paper, which showed online teachers rated themselves highest in PK, CK and PCK, with strong PK–CK correlations but weak connections in TPK and TCK (Archambault & Crippen, 2009).

Markauskaite et al. (2011) explored different knowledge used by e-learning design teams in higher education by observation and identified six additional technology-related knowledge bases, including technology-related curriculum knowledge, learner characteristics knowledge, educational contexts knowledge, educational ends knowledge, technological design knowledge and process knowledge. Their study drew on these categories as an analytic lens to identify the kinds of knowledge teachers mobilise and how they combine them in practice, extending beyond the original theory-based TPACK knowledge base categories. Markauskaite et al.'s study is highly relevant to our study as it investigated knowledge enacted in practice rather than relying on self-reported data.

Scherer et al. (2017) investigated the construct validity of TPACK by looking specifically into the T-dimensions (TCK, TPK, TPCK and TK). A survey was conducted among 665 pre-service teachers in Belgium to investigate their self-efficacy in their technological knowledge. Their study found the four knowledge bases could not be disentangled empirically, and they raised a question on "whether or not structural relations among the T-dimensions exist" (Scherer et al., 2017, p. 13).

Overall, these empirical findings reinforce the complexity of TPACK as a practical construct, highlighting both its developmental potential and the ongoing challenges of measurement and domain differentiation.

Gaps in research and the contribution of this study

Despite the breadth of TPACK scholarship, most empirical studies in TPACK research have relied heavily on self-report surveys (e.g., the instrument Schmidt et al. developed in 2009) and quantitative analyses such as correlation and factor analysis (Willermark, 2018; Zou et al., 2022). Although these research methods dominate the field, they primarily captured teachers' perceptions of their own knowledge rather than their actual practice, making it difficult for researchers to discover whether additional knowledge bases exist or how teachers integrate them in different teaching contexts.

Accordingly, two gaps were explored. First, there is limited evidence on the full range of knowledge bases teachers draw upon beyond traditional TPACK, particularly forms of knowledge often subsumed under context. Second, there is limited empirical detail on how teachers combine multiple knowledge bases across planning and instruction and what prompts those combinations.

This study addressed these gaps through observation-based analysis. It did not seek to redefine TPACK conceptually; rather, it identified additional knowledge bases teachers mobilise in practice beyond traditional TPACK, mapped how these knowledge bases co-occur during planning and instruction and examined the factors that shape their combination across contexts.

Methodology

Data collection

A case study approach was used for this research. It was conducted in accordance with relevant ethical guidelines and received approval from the appropriate institutional ethics committee, with all participants providing informed consent. Pseudonyms are used for all participants to ensure confidentiality.
The first set of data, planning context, was collected through think-aloud observations of eight tertiary educators from an Australian university when they were planning their lessons to teach pre-service teachers. Each educator was observed three times. The planning sessions lasted from 45 minutes to 1 hour.

The second set of data, teaching context, was collected through classroom observations. The observations only included educators when they were teaching pre-service teachers. Each educator was observed three times during 1 semester in 90 minute classes.

Data analysis

The data were analysed through both qualitative and quantitative methods. While a broad range of utterances were observed, the coding scheme used was developed to identify high frequency teacher practices when planning or delivery lessons and is meant to capture glimpses into potential knowledge bases teachers use. The goal was not to extensively classify every utterance, and various observations of idiosyncratic, unclear and low frequency potential knowledge bases were not included in the coding scheme.

While this coding scheme and the results from it increase the complexity, this was done with the purpose of defining important and useful knowledge bases found in teaching practice to better transform the theoretical TPACK framework into a practical model which is fit for purpose. The goal was not to systematically classify every utterance – avoided needless complexity while adding clarity.

To perform the qualitative analysis, transcriptions of think-aloud observations were recorded verbatim. Classroom observations were analysed directly and recorded with allocations to knowledge base categories made without using transcriptions. We read the extensive field notes created during the time of data collection and watched the videos several times prior to analysis. Based on emergent themes from the data, planning and teaching sessions were categorised into episodes:

- planning sessions: timetabling, content related decisions, teaching methods and strategies, technology integration and assessments
- teaching: recalling prior knowledge, introduction and delivery, classroom activities, review and closure.

A coding scheme was developed based on all original knowledge bases and their combinations from Shulman (1986, 1987), Mishra and Koehler (2006) and Markauskaite et al. (2011). The knowledge bases were categorised into two types based on the literature:

- Core knowledge bases encompassed the principal knowledge domains from PCK and TPACK framework including content, pedagogy, technology, curriculum and knowledge of learner characteristics.
- Combined knowledge bases included the meaningful integration of two or three knowledge bases, such as how pedagogical design knowledge (PDK) emerged through the combination of pedagogical knowledge (PK) and design knowledge (DK). It was important to examine why two or more knowledge bases were classified as combined and why several mentions to knowledge categories were considered as core knowledge bases. A knowledge base was considered a combined knowledge base only when the teachers purposefully or meaningfully integrated them to make a decision about teaching, learning or assessment.

Table 1 shows an example of a combined knowledge base in the left column and the use of two core knowledge bases in right column.

Table 1
An example comparing a combined knowledge base and drawing on two knowledge bases sequentially

Combined knowledge base	Sequentially drawing on two core knowledge bases
I decided to replace the group activity for algebra topic as it's simple and can be done through a simple individual reflection [PCK]. (Ana, TA)	Fractions is a pretty complex topic, it’s really hard to understand how a numerical quantity can be a part of the whole number (CK), it’s hard for them, it’s a hard topic. Um, let me think about strategies that I’m gonna choose from like lectures, or discussions kinda stuff [PK]. (Ana, TA)

Note. TA = think aloud.

In Table 1, the left column shows how two knowledge bases are combined to make a purposeful decision about student learning. The right-hand column indicates the reference to two core knowledge bases, but a purposeful integration is not present.

The whole coding scheme with both core and combined knowledge bases is not presented here due to its length. However, Table 2 provides a brief overview of core knowledge bases only and how they were defined in this research to identify them in observational data, though not all were observed with meaningful frequency. A combined knowledge base was a meaningful integration of two or more of the following categories.

Table 2
Knowledge bases, their definitions and examples

Knowledge base	Definition	Examples
Curriculum	Knowledge of how to achieve the alignment between the programme or course learning outcomes with various other elements of the course	Australian Qualifications Framework or accreditation standards or programme-level expectations, aligning learning outcomes, mapping assessments to outcomes, sequencing topics logically
Content	Knowledge of the subject matter	Data literacy, Newton’s laws of motion, supply–demand curves, SQL joins, photosynthesis pathways
Pedagogy	Knowledge of teaching methods and how students learn	Problem based learning, retrieval practice, scaffolding, formative feedback strategies, cooperative learning structures, cognitive load management

Knowledge base	Definition	Examples
Technology	Knowledge of digital tools and technologies	Learning management system features, Microsoft Zoom or Teams breakout rooms, H5P interactive content, Turnitin settings, Padlet, Microsoft PowerPoint
Design	Knowledge of instructional design models and frameworks that can help design experiences for better student learning	Cognitive load theory, analyse, design, develop, implement and evaluate model, learning maps, pacing and sequencing
Learner characteristics	Knowledge of learners' backgrounds, their prior knowledge and perceptions they hold about a particular learning setting	Prior study or work experience, English language considerations, accessibility requirements, cultural background, health and well-being factors
Educational contexts	Knowledge of different social, cultural, environmental and institutional settings in which learning takes place	Institutional policies, academic integrity rules, resource availability, class size caps
Educational ends	Knowledge of the broader aims of education and values that the teacher thinks students should develop	Fostering critical thinking, ethical decision-making, civic responsibility, graduate employability

The validity of this coding scheme was tested and adapted by sharing the coding scheme with another expert researcher in the field for their review, with coders reaching agreement on approximately 89% of the coded items, indicating a high level of consistency in the application of the coding categories.
Each episode from planning and teaching was then extensively analysed to identify teachers' use of knowledge bases using the coding scheme. Combinations of categories emerged from observations, though not every possible knowledge base or combined category was observed or classified through analysis.

A quantitative descriptive analysis was used to identify broad frequency trends across categories. The observation set generated over 900 classified utterances, and these were quantised in line with our research goals of improving classifications and defining important and widely practiced knowledge base categories which were not adequately differentiated or addressed in the original TPACK framework (Mishra & Koehler, 2006). Basic statistical trends to count and examine the importance and frequency from various perspectives were done, while more detailed analytical metrics were not applied due to the limits of validity with observing only eight educators and the scope of the research questions.

Results

Based on the research questions, the following key findings were generated through the analysis of the data:

- In every observed episode of planning and teaching sessions, the knowledge bases teachers drew upon went beyond the seven knowledge bases and combinations in the original TPACK framework (Mishra & Koehler, 2006) and those described by Shulman's (1986, 1987) framework and Markauskaite et al.'s (2011) framework, which our coding scheme was based on. Eight new combinations of knowledge bases were found, which will be referred to as TPACK in context categories.
- Teachers relied on both core and combined knowledge bases.

- Teachers drew on various knowledge bases with marked different frequencies, and this was sensitive to the planning and teaching contexts. Noteworthy variations were found in the rates of various core and combined knowledge bases when planning compared to when teaching.
- In the teaching context, 60% of observed behaviour fit into traditional TPACK knowledge bases, while in the planning context, only 25% of their think-aloud utterances fit into the traditional TPACK knowledge bases. The preponderance of TPACK in context knowledge bases in planning comprised 75% of think-aloud utterances across 902 observations.

TPACK and beyond

Table 3 presents the descriptions and examples of eight new knowledge bases found in this research in addition to the knowledge bases from the PCK framework (Shulman, 1987), TPACK framework (Mishra & Koehler, 2006) and Markauskaite et al.'s (2011) knowledge bases. No evidence of educational ends knowledge from Markauskaite et al.'s knowledge bases was found. An emergent new category found is the reflection knowledge base. Notably, some core knowledge bases from the TPACK in context categories did not occur independently. Reflection is one of those categories which was always combined with other categories, such as pedagogy or technology, resulting in new combinations (e.g., pedagogical reflection knowledge, technological reflection knowledge). Knowledge of reflection in this research is referred to as the knowledge of thinking about one's own thinking, experiences and practices. Similarly, the curriculum knowledge base was only observed in combination with other knowledge bases.

Table 3
New knowledge bases, their descriptions and examples from data

Knowledge bases	Description	Examples from TA and classroom observations (CO)
1. Pedagogical design knowledge (PDK)	PDK emerged through the combination of core knowledge bases such as pedagogical knowledge and design knowledge, showing teachers' knowledge and understanding of designing learning task(s) to be used in the classroom, such as designing an inquiry task, designing problem-solving tasks.	So I'm gonna now design that task and um I'm gonna follow certain steps involved in um task design um so um I'll ask them to pick up a topic, write at least three instructional objectives, show it to your work partner and look at their objectives, provide feedback and get feedback, implement peer feedback, pick up one objective to show it to the whole class, explain its characteristics and how did you implement your peer's feedback. (Ana, TA)
2. Pedagogical reflection knowledge (PRK)	PRK emerged through the combination of knowledge of pedagogy and knowledge of reflection that shows teachers' knowledge and understanding of various reflective techniques and how to use them to reflect on pedagogical practices.	Um where I've put my reflective journal – here you go, um this journal from the last year is gonna be like a guide what worked well and what didn't that I need to change. (Karen, TA)
3. Technological reflection knowledge (TRK)	TRK emerged through the combination of reflection knowledge and technological knowledge: how to use the various technological tools and resources (eg., software programmes, blogs, wikis, websites) to improve their usage in future teaching and learning situations.	Um I've to choose from blogs and online discussion forums from last year to see um which one I'm gonna drop this year um which one worked and which wasn't really um useful so let me open the links of both to really reflect on both before having that decided. (James, TA)

Knowledge bases	Description	Examples from TA and classroom observations (CO)
		When you start planning your courses you've to reflect on technologies that you found useful or not really useful before using them again in classrooms. (Mary, CO)
4. Technological pedagogical reflection knowledge (TPRK)	TPRK emerged through the combination of three core knowledge bases: technological knowledge, pedagogical knowledge and reflection knowledge. This involves teachers' knowledge about the use of tools and reflection techniques (reflective diaries, blogs, journals or other sources of reflection) in terms of how they taught in past years.	This Prezi is from last year um I'd noted some points soon after lecture last year on one of the slides that I always do um I've to find, oh it's the last slide, yeah so I've to [40 seconds pause] oh now I remember I had decided not to use Prezi this year. (David, TA)
5. Pedagogical educational contexts knowledge (PECK)	PECK, which emerged through the combination of pedagogical knowledge and educational contexts knowledge, involves teachers' knowledge and understanding of which pedagogical approaches are appropriate in a particular educational context (e.g., discipline, school and university).	I'm teaching science so I've to look for the approaches like inquiry or hands on experiments kinda things. (Susan, TA) You're pre-service teachers so it's a different context for use of pedagogical approaches it's different to how we teach in a school context. (Sylvia, CO)
6. Reflection learner characteristics knowledge (RLCK)	RLCK reflects teachers' knowledge and understanding of how they met the individual differences in previous years. This knowledge base emerged through teachers' knowledge of reflection and learner characteristics.	Oh hold on, I remember um from last year that that there was a student with – who had some learning disability, so I had to do grouping accordingly, I've got his record with me which I've to look which group I assigned him to and why. (Rose, TA)
7. Pedagogical learner characteristics knowledge (PLCK)	This knowledge base, PLCK, is a combination of pedagogical knowledge and learner characteristics knowledge, which shows teachers' knowledge and understanding of meeting individual differences through the use of various pedagogical methods and approaches.	I've to make sure that those who are not confident with using this approach [teaching demonstration], how I'm gonna prepare them for that. (Mary, TA) Guys I'm now gonna make some mix ability groups based on this list I prepared. (David, CO)
8. Pedagogical curriculum knowledge (PCuK)	PCuK emerged when teachers combined their pedagogical knowledge with curriculum knowledge in terms of what they know about curriculum and how they are going to implement it in their pedagogical practices.	Um these dot points are the learning outcomes from the syllabus that I've to make sure that I want um to achieve through the use of pedagogical approaches I'm gonna use. (Susan, TA)

The evidence of these combinations was consistently found across all eight teachers' think-aloud and classroom observations. Only those combinations that occurred repeatedly across all episodes were considered as knowledge bases. If a combination occurred only once or twice and was not commonly found, it was not considered as a valid or widely meaningful knowledge base combination.

Combination of knowledge bases

The planning and teaching contexts were individually allocated knowledge bases through observation. This was often not the same with significant differences in the frequency of usage of a given knowledge base between planning and delivery. One implication of this is the application of metacognition as a teacher skill in this selection process, not simply the availability or richness of their experience in a specific knowledge base. For example, a teacher might more often rely on a given knowledge base, such as pedagogy, when they have a weakness in another area, such as technology or curriculum, though they could choose to lean into a more relevant knowledge base they are weaker in, if there is a need to do so in a particular lesson. Effective planning and teaching may rely on both a broad richness of capability in varied knowledge bases and applied metacognition for the appropriate selection and application of those knowledge bases to a given teaching scenario or goal. This is a broader discussion and is not the focus of this paper. However, it is worth mentioning to provide evidence of the observed selection process.

The core knowledge bases observed were curriculum, content, pedagogy, learner characteristics and technology. Figure 1 presents an observed process in which teachers drew upon a range of knowledge bases, then selected and sequenced them according to the specific teaching context and goals in order to construct effective solutions to discrete pedagogical challenges.

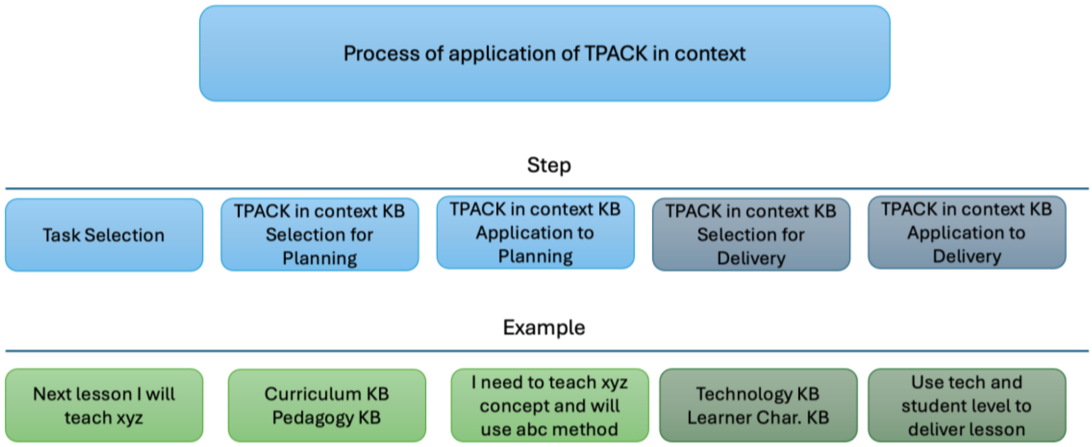
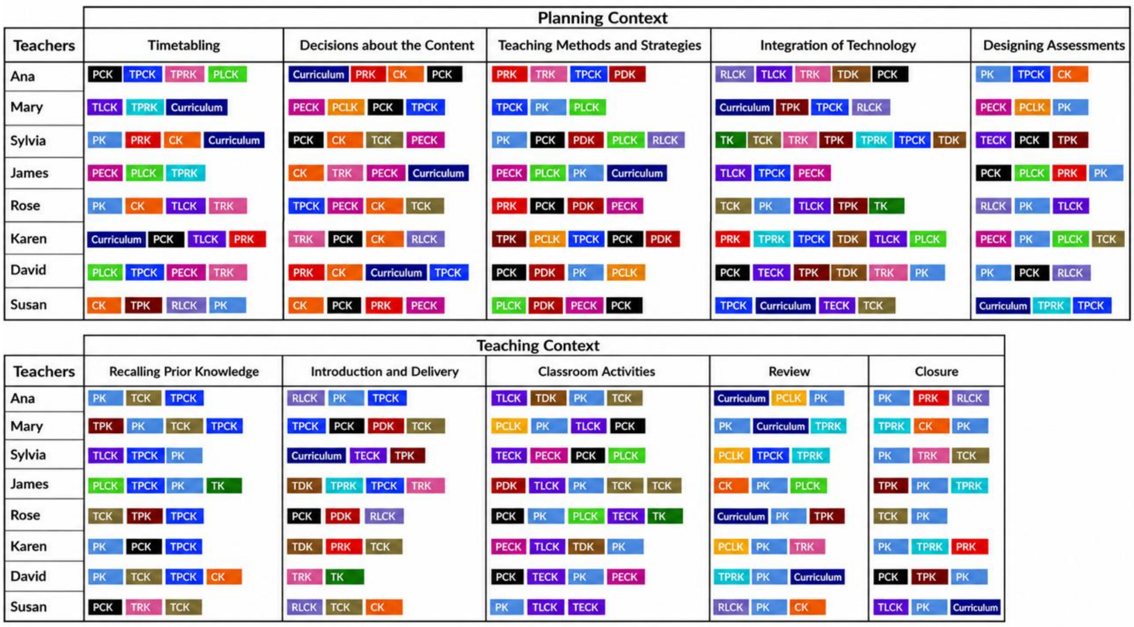


Figure 1. Process of application of TPACK in context

TPACK in context – planning versus teaching context

Through the investigation of teachers' planning and teaching processes, we found that the combinations of knowledge bases that underpinned their planning and teaching decisions to integrate information and communications technology in teaching differed in planning versus teaching contexts. Variations in the way teachers drew upon their knowledge bases occurred between one episode and another within the planning or teaching contexts; the teachers were observed demonstrating creative flexibility and task orientation rather than rigid or routine workflows or habits. Figure 2 provides a visual summary of variations in teachers' combinations of knowledge bases across various episodes in planning and teaching contexts.



Teachers	Planning Context: Timetabling	Decisions about the Content	Teaching Methods and Strategies	Integration of Technology	Designing Assessments
Ana	PCK TPCK TPRK PLCK	Curriculum PRK CK PCK	PRK TRK TPCK PDK	RLCK TLCK TRK TDK PCK	PK TPCK CK
Mary	TLCK TPRK Curriculum	PECK PCLK PCK TPCK	TPCK PK PLCK	Curriculum TPK TPCK RLCK	PECK PCLK PK
Sylvia	PK PRK CK Curriculum	PCK CK TCK PECK	PK PCK PDK PLCK RLCK	TK TCK TRK TPK TPRK TPCK TDK	TECK PCK TPK
James	PECK PLCK TPRK	CK TRK PECK Curriculum	PECK PLCK PK Curriculum	TLCK TPCK PECK	PCK PLCK PRK PK
Rose	PK CK TLCK TRK	TPCK PECK CK TCK	PRK PCK PDK PECK	TCK PK TLCK TPK TK	RLCK PK TLCK
Karen	Curriculum PCK TLCK PRK	TRK PCK CK RLCK	TPK PCLK TPCK PCK PDK	PRK TPRK TPCK TDK TLCK PLCK	PECK PK PLCK TCK
David	PLCK TPCK PECK TRK	PRK CK Curriculum TPCK	PCK PDK PK PCLK	PCK TECK TPK TDK TRK PK	PK PCK RLCK
Susan	CK TPK RLCK PK	CK PCK PRK PECK	PLCK PDK PECK PCK	TPCK Curriculum TECK TCK	Curriculum TPRK TPCK

Teachers	Teaching Context: Recalling Prior Knowledge	Introduction and Delivery	Classroom Activities	Review	Closure
Ana	PK TCK TPCK	RLCK PK TPCK	TLCK TDK PK TCK	Curriculum PCLK PK	PK PRK RLCK
Mary	TPK PK TCK TPCK	TPCK PCK PDK TCK	PCLK PK TLCK PCK	PK Curriculum TPRK	TPRK CK PK
Sylvia	TLCK TPCK PK	Curriculum TECK TPK	TECK PECK PCK PLCK	PCLK TPCK TPRK	PK TRK TCK
James	PLCK TPCK PK TK	TDK TPRK TPCK TRK	PDK TLCK PK TCK TCK	CK PK PLCK	TPK PK TPRK
Rose	TCK TPK TPCK	PCK PDK RLCK	PCK PK PLCK TECK TK	Curriculum PK TPK	TCK PK
Karen	PK PCK TPCK	TDK PRK TCK	PECK TLCK TDK PK	PCLK PK TRK	PK TPRK PRK
David	PK TCK TPCK CK	TRK TK	PCK TECK PK PECK	TPRK PK Curriculum	PCK TPK PK
Susan	PCK TRK TCK	RLCK TCK CK	PK TLCK TECK	RLCK PK CK	TLCK PK Curriculum

Figure 2. Variations in knowledge base selection by teacher, context and task

Below are presented specific examples of think-aloud utterances from the planning sessions from one participant, Sylvia.

Teaching methods and strategies episode

This episode shows how Sylvia drew upon five knowledge bases that included one core knowledge base, PK, and several combined knowledge bases, such as PCK, PDK, PLCK and RLCK:

> I'm not gonna stand and speak for sure, so I need some kinda activities like mental calculations or brainstorming stuff in lectures and discussions and practical activities kinda stuff in tutorials it'd be a great idea to go. [PK]
>
> Right, so now I'm gonna make a column next to the "content" column where I'm gonna add how I'm gonna teach these topics. [PCK]
>
> I'll need to make my lesson goals crystal clear … ok um brainstorming questions … then we'll move forward to the next problem. [PDK]
>
> So I really need to make sure that learning needs of everyone sitting in my class are fulfilled through these teaching methods and strategies. [PLCK]
>
> I've to do what my students like, as I always did um in past years. I've always focused on what my students find useful. [RLCK]

Figure 3 illustrates the combinations of knowledge bases from Sylvia's teaching methods and strategies episode:

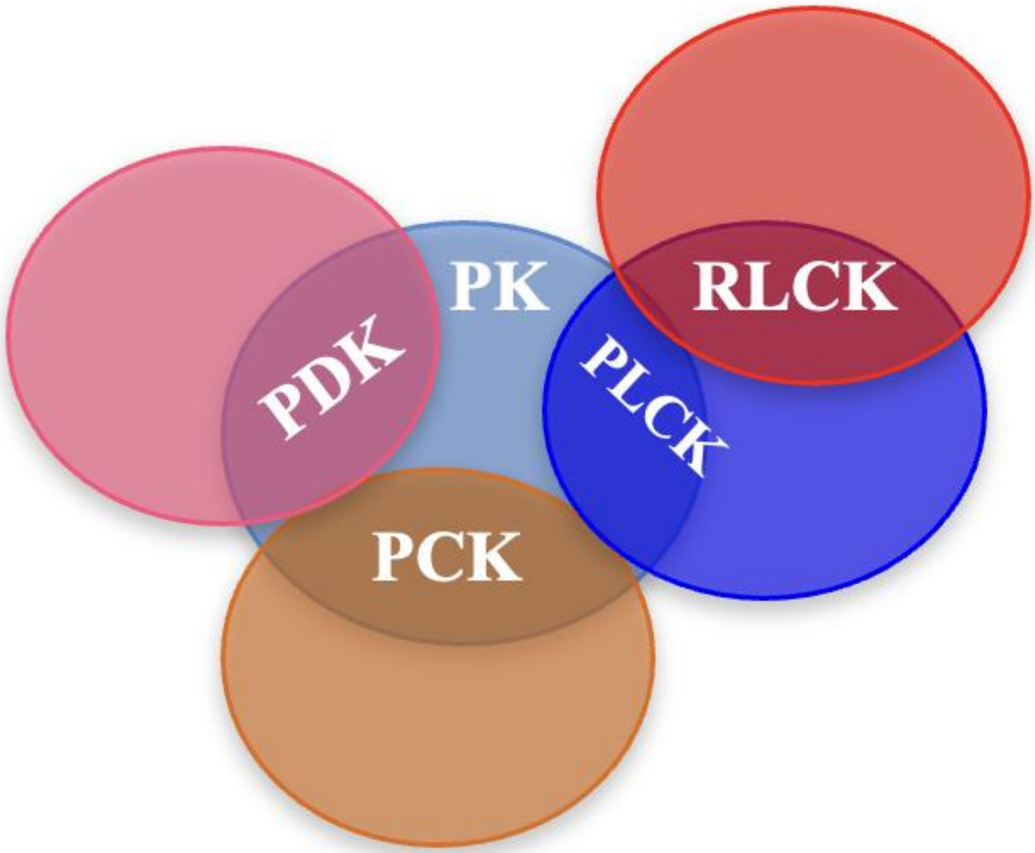


Figure 3. A summary of knowledge bases Sylvia drew upon in the teaching methods and strategies episode

Integration of technology episode

In the integration of technology episode, Sylvia drew upon TK, TPRK, TPK, TPCK, TCK, TRK and TDK:

> Technology um technology um I've checked [interactive whiteboards] in the labs downstairs are fully functional now and the software that goes with it is already installed on computers [TK].
>
> Last year I got them to collaborate online using err wiki, each year I get them to collaborate using wiki [TPRK]. I'll set up a wiki space this year for each group of four and give them a collaborative task using wiki [TPK]. Oh and I can use YouTube videos in the beginning of the lectures, as they're good help for them to revise the topics they've already learnt. [TPCK]
>
> I've got some simulations on geometry that show how angles work, I've got some YouTube videos and some interactive games on um probability. [TCK]
>
> What did I use last year … um I use this e-learning site that's a great tool to keep a record of past years' practices [TRK], so I'll have a look on it to see what um which tools were really useful and what needs to be replaced.
>
> I'll have to integrate design principles while designing my presentations, like coherence, presentation of information, use multimedia objects. [TDK]

Figure 4 shows the combinations of knowledge bases from Sylvia's integration of technology episode:

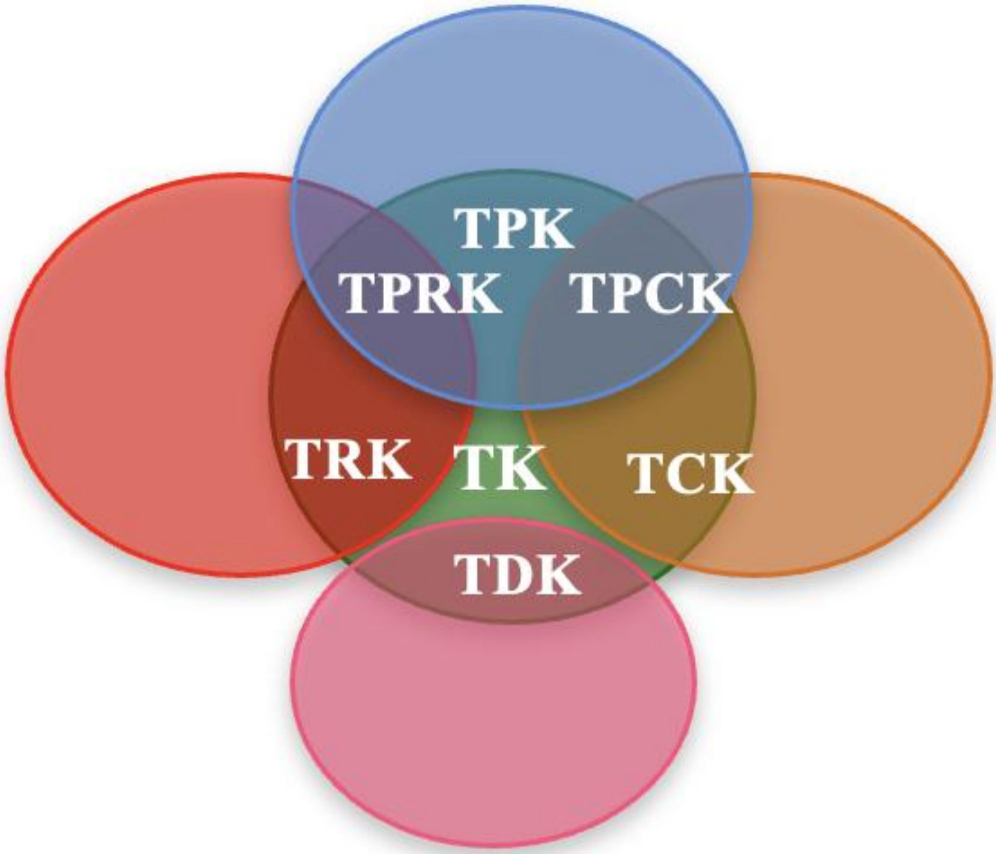


Figure 4. A summary of knowledge bases Sylvia drew upon in the integration of technology episode

The above results indicate a highly contextual nature of teachers' planning and teaching decisions. Below are quantitative results that help validate and extend the qualitative interpretations.

Observations of teacher utterances were split into 19 different combinations with a division made between planning and teaching. These 19 categories were based on empirical observation and were either a single, double or triple combination of TPACK and TPACK in context categories (see Table 4).

Table 4
Count and percentage of utterances by observation category

Category	Knowledge bases	Planning context		Teaching context		Total	
		TA		CO			
		No.	%	No.	%	No.	%
TPACK in context – core	1. Curriculum knowledge (CuK)	93	10%	17	3%	110	7%
TPACK – core	2. Content knowledge (CK)	73	8%	19	3%	92	6%
TPACK – core	3. Pedagogical knowledge (PK)	21	2%	72	11%	93	6%
TPACK – core	4. Technological knowledge (TK)	48	5%	13	2%	61	4%

Category	Knowledge bases	Planning context TA		Teaching context CO		Total	
		No.	%	No.	%	No.	%
TPACK – duo	5. Pedagogical content knowledge (PCK)	20	2%	152	23%	172	11%
TPACK – duo	6. Technological pedagogical knowledge (TPK)	11	1%	32	5%	43	3%
TPACK – duo	7. Technological content knowledge (TCK)	39	4%	45	7%	84	5%
TPACK – trio	8. Technological pedagogical content knowledge (TPCK)	26	3%	57	9%	83	5%
TPACK in context – duo	9. Technological educational context knowledge (TECK)	56	6%	34	5%	90	6%
TPACK in context – duo	10. Technological learner characteristics knowledge (TLCK)	43	5%	26	4%	69	4%
TPACK in context - duo	11. Technological design knowledge (TDK)	73	8%	19	3%	92	6%
TPACK in context – Duo	12. Pedagogical design knowledge (PDK)	72	8%	21	3%	93	6%
TPACK in context – duo	13. Pedagogical reflection knowledge (PRK)	72	8%	10	2%	82	5%
TPACK in context – duo	14. Technological reflection knowledge (TRK)	56	6%	17	3%	73	5%
TPACK in context – duo	15. Pedagogical educational context knowledge (PECK)	43	5%	40	6%	83	5%
TPACK in context – duo	16. Reflection learner characteristics knowledge (RLCK)	52	6%	17	3%	69	4%
TPACK in context – duo	17. Pedagogical learner characteristics knowledge (PLCK)	78	9%	34	5%	112	7%
TPACK in context – duo	18. Pedagogical curriculum knowledge (PCuK)	7	1%	18	3%	25	2%
TPACK in context – trio	19. Technological pedagogical reflection knowledge (TPRK)	19	2%	20	3%	39	2%
	Total	902	100%	663	100%	1565	100%

A salient finding from this data comes from the comparison between the traditional TPACK knowledge domains and the TPACK in context ones we observed. Overall, 59% of all observed utterances did not fit into the TPACK framework, which comprised an even greater majority of 74% of planning utterances.

As shown in Table 5, a large observational difference between planning and teaching was found with a delta of 31% between the 75% TPACK in context in planning compared to the 43% in teaching delivery of TPACK in context knowledge bases.

Table 5
Count and percentage of planning context utterances (PC), teaching context (TC) and total (T) based on either TPACK knowledge bases or TPACK in context knowledge bases

Category	Sum of PC no.	Sum of PC %	Sum of TC no.	Sum of TC %	Sum of T no.	Sum of T %
In context total	664	74%	273	43%	937	59%
TPACK total	238	25%	390	60%	628	40%
Total	902	99%	663	103%	1565	99%

Note. Totals above or under 100 were due to rounding error accumulation across the 19 categories.

Table 6 differentiates how often these knowledge bases were part of planning, teaching or total utterances. The X/19 column shows the total number of times out of the 19 knowledge base was present either by itself or in a combination duo or trio. Notably, the content knowledge base appeared far less frequently than the other two original TPACK knowledge bases. Amongst the in context expanded knowledge bases, reflection, design and learner characteristics were the most frequently observed. Every single knowledge base was observed to appear above 10% of the time in either the planning or delivery context, indicating their importance to teachers. Reflection and learner characteristics in particular were the only two in context knowledge bases which appeared more often than the original TPACK knowledge base content in the planning context with the design knowledge base also appearing nearly as frequently as content.

Table 6
Percentage of times each single knowledge base appears in the data

TPACK in context	PC %	TC %	T %	X/19
Curriculum knowledge	11	6	9	2
Reflection	22	11	16	4
Design	16	6	12	2
Learner characteristics	20	12	15	3
Educational context	11	11	11	2
TPACK	PC %	TC %	T %	X/19
Content	17	42	27	4
Pedagogy	41	70	52	10
Technology	40	41	40	9

Note. The totals intentionally exceed 100% due to this counting of individual knowledge bases, which includes their singular and combined double or triple categories.

Discussion

Additional knowledge bases by observation

The findings obtained through the observation of teachers in planning and teaching contexts indicate teachers drew upon a wide range of 19 knowledge bases, both core and combined, when making their information and communications technology -related planning and teaching decisions. Of these 19 knowledge bases, only eight were included in the initial frameworks – PCK (Shulman, 1986, 1987) and TPACK (Mishra & Koehler, 2006) – and Markauskaite et al.'s (2011) knowledge bases. These frameworks were helpful in identifying some core and combined knowledge bases. However, evidence for one of

Shulman's (1987) knowledge bases, knowledge of education ends, could not be found, as it was hard to differentiate between educational purposes (from the educational ends domain) and learning outcomes (from the curriculum design domain).

The results resonate with the findings of Lee and Tsai (2010), who argued that TPACK alone may not be sufficient for providing adequate understanding of applied teaching practices using technology. Our results similarly showed additional knowledge bases, indicating teachers do not rely solely on TPACK when making planning and teaching decisions when using technology in the classroom.

In addition to the PCK and TPACK frameworks' knowledge bases, some of the knowledge bases resembled Markauskaite et al.'s (2011) technology-related knowledge bases, which included technological educational context knowledge, technological learner characteristics knowledge and technological design knowledge. Although Markauskaite et al. found evidence of five new knowledge bases including the above three, their other two knowledge bases – technological educational curriculum knowledge and technological educational ends knowledge – were not observed in this research.

A major gap was found in the existing research in how past studies mainly relied on self-report surveys based on Schmidt et al.'s (2009) instrument. Such instruments make it difficult to determine whether additional knowledge bases exist beyond the seven TPACK domains and how teachers draw on knowledge bases in practice. This research addressed this gap by leveraging observational and first principles analysis of teacher behaviour before applying any frameworks.

Beginning with a non-prescriptive observational approach allowed for the capture of these common and recurrent teaching practices, which were likely observed and possibly either discarded or inappropriately labelled in other studies. In this study, only a small percentage of ambiguous and infrequent utterances by teachers were discarded for being unclear or idiosyncratic to a particular teacher or seen as an unclear moment in their planning. Greater coverage of frequently observed behaviours may offer more insight into teachers' internal processes using the proposed taxonomy. The additional in context knowledge bases were integral to planning and delivery, and they appeared in every single lesson observed.

Importance of additional knowledge bases

Our results indicate these other knowledge bases are important and relevant for effective teaching and are vital to teachers. This is supported by the extensive time and frequency in which teachers invest effort into these other TPACK in context domains to organise their planning and delivery of lessons. These are seemingly not erroneous or wasteful practices where teachers are off course, as their goals were to be effective in their teaching with technology rather than to narrowly apply a particular framework. The overall lesson quality and purpose in design must be developed in tandem with delivery considerations, which include the use of technology and other resources.

The inclusion of technology-assisted methods in teacher training, practical considerations and institutional and curricular demands on teachers match with these observed patterns, which elevate teaching with technology into a broader category of teaching in general. Real practices and essential teaching considerations around reflection, design, learner characteristics, educational context and curriculum can readily be seen as important across educational research and cannot reasonably be excluded when technology happens to be a component in a planned lesson.

A search through the literature will return tens or hundreds of thousands of results in each of these areas of pedagogical concern. This supports our observations that teachers take a holistic approach and will apply any of their relevant knowledge bases when planning and delivering lessons using technology. One could readily predict poor lesson quality if a teacher did not effectively select and apply their knowledge bases concerning curriculum directions, reflection on prior teaching experiences, broad design beyond direct pedagogy, understanding of their learners and the context in which they are teaching. What to teach, at what level, to whom and how to present it and relying on accumulated experience are core teaching practices relevant with or without the additional context of technology use. These additional knowledge bases in this TPACK in context framework operate in concert and often in combination with the original TPACK framework knowledge bases.

Process of combining knowledge bases and indications of metacognition

A metacognitive skillset that includes the behaviours of setting goals, selecting appropriate knowledge bases and then applying those knowledge bases towards either a planning or delivery application were also found to be noteworthy.

Teachers must develop these essential metacognitive capabilities, as it is not intrinsically obvious which knowledge base or a combination of them to apply to a given scenario (Jiang et al., 2016). There are usually variable and multiple valid solutions or approaches as one size does not fit all, nor is there a single best teaching design process. We found that context, purpose and task orientation were the major factors that influenced the metacognitive processes of how teachers drew upon various combinations of knowledge bases. This resonates with the contextualised TPACK, which integrates PK and PCK into pedagogical content knowledge in context; and TPK, TCK and TPCK into technological content knowledge in context (Jang & Tsai, 2013).

We do not consider the observed 19 combinations as a limitation, and it is likely that a group of teachers facing a different context might utilise combinations not observed in this study. We understand the metacognitive process of selecting and applying knowledge bases to be a dynamic process to solve emergent teaching scenarios. In this study, the teachers were not undergoing significant curriculum change pressures; if that were the case, we would anticipate that teachers would choose to draw more heavily from the curriculum knowledge base or its combinations, though some boundaries are probable with certain combinations being unlikely to ever become practically relevant to a teacher.

Future directions

Around 60% of teaching practices in this study were found to fit into the proposed TPACK in context model. Further study and research approaches could benefit from these findings by being more oriented towards observational studies, exploration of metacognitive skills and examination of the knowledge bases underlying TPACK. Exploration and a deeper understanding of these aspects of teaching with technology could provide benefits in teacher training and professional development by focusing on the practical challenges teachers solve in their planning and delivery.

Further studies might explore whether teachers who lack in a specific knowledge base may more readily lean into their strengths to develop their lessons. Teachers do not comprise a homogeneous population with equally strong capabilities in all areas. The metacognitive application of a dynamic and creative TPACK in context knowledge bases framework could be more accurate in describing real-world teaching practices.

Future explorations of any of these TPACK in context knowledge bases could lead to a better understanding of real-world teacher practices around the use of technology in education. While this study is quite preliminary and broad in scope, further examination and deeper understanding of each of these TPACK in context knowledge bases could bring value in understanding how teachers plan and delivery lessons using technology.

Author contributions

Shaista Bibi: Project administration, Methodology, Investigation, Conceptualisation; Data curation, Formal analysis, Writing – original draft, Writing – review and editing, Validation, Visualisation; **Kevin Samnick:** Data curation, Formal analysis, Writing – original draft, Writing – review and editing, Validation, Visualisation; **Vivian Liu:** Data curation, Formal analysis, Writing – original draft, Writing – review and editing, Validation, Visualisation.

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