ARTICLE

Bridging the Gap: Teaching Paper-Based Geographic Information Systems through information and communication technology integration in secondary schools

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ABSTRACT

Geographic Information Systems (GIS) are crucial in modern Geography education, cultivating spatial thinking and data analysis skills. While included as a core topic in school curricula, many under-resourced secondary schools in South Africa still depend on Paper-Based Geographic Information Systems (PBGIS) methods due to limited access to digital tools and infrastructure. This study explores how Information and Communication Technology (ICT) can support the teaching of PBGIS in secondary schools. Guided by the Technological, Pedagogical, and Content Knowledge (TPACK) framework, the study examines how these knowledge domains interact to enhance teaching effectiveness. In this study, data were collected through semi-structured interviews with six Geography teachers from three South African secondary schools in which PBGIS teaching is integrated with ICT. The results show that projectors, computers and internet access, and GIS software such as QGIS and ArcGIS, can enhance PBGIS teaching. A blended approach that integrates PBGIS with ICT tools is recommended. This should be driven by partnerships between the Department of Basic Education, geospatial and educational technology sectors, universities, teacher training institutions, and NGOs to build teacher capacity and ensure effective curriculum integration.

Keywords: Geography education, ICT integration, paper-based Geographic Information Systems, TPACK, Under-resourced schools

INTRODUCTION

Geographic Information Systems (GIS) have become essential to modern Geography education, equipping learners with spatial thinking skills and the ability to analyse and interpret geographic data. South Africa's Curriculum and Assessment Policy Statement (CAPS) includes GIS as a core topic (Mkhongi & Musakwa 2020; Manik 2022; Kriel & van der Merwe, 2025). However, many schools particularly in under-resourced or rural areas continue to rely on paper-based GIS (PBGIS) teaching methods due to limited access to computers, software and internet connectivity (Fleming 2021; Gubevu 2025). While PBGIS lacks the interactivity and dynamic capabilities of digital GIS tools, it is more challenging for learners to grasp complex spatial concepts such as layering, buffering, and spatial analysis. This can place learners at a disadvantage, particularly when the curriculum assumes a level of Information and Communication Technology (ICT) access and competence that does not reflect on-the-ground realities. In South Africa, this marked by stark inequalities in access to computers, reliable internet connectivity, and digital teaching resources, especially between urban and rural or under-resourced schools.

In addition, the increasing availability of basic digital tools such as smartphones, offline apps, and low-cost laptops presents new opportunities to integrate ICT into PBGIS teaching, even in schools with limited resources. Teachers can creatively combine traditional teaching methods with ICT tools to make GIS learning more interactive, accessible and meaningful for learners (Kadhim 2020). Despite these possibilities, there is a lack of research on how ICT can enhance the teaching of PBGIS in low-resource educational settings. This study addresses that gap by investigating the realities of PBGIS teaching in selected secondary schools in KwaZulu-Natal Province, South Africa.

THE GIS AND PBGIS LANDSCAPE IN AFRICAN SCHOOLS

GIS education is still a relatively new and emerging field in southern Africa (Mzuza & Van der Westhuizen 2019). GIS supports decision-making, critical thinking, and inquiry-based, learner-centred learning, thereby enhancing educational quality. In order to deliver this in schools, there is a need for teachers and policymakers to strengthen the inclusion of GIS in teacher-training programmes and to adopt relevant pedagogical skills to improve GIS education across the region (Mzuza & Van der Westhuizen 2019; Mkhongi & Musakwa 2020). GIS education has been envisioned as a strategy that can contribute to new teaching, learning, and understanding methods, but this is constrained by inadequate resources and limited exposure of learners to GIS's practical uses (Mkhongi & Musakwa 2020). This also comes about through a lack of reliable power, internet connection, computer system, accessories and appropriate software (Sumari et al. 2018).

Several studies have highlighted the challenges of implementing GIS education in South African schools. Gaps in teacher training and resource availability are barriers to effective GIS teaching (Mkhongi & Musakwa 2020; Mkhize 2023a, 2023b). Yıldırım & Ünlü (2021) highlight a lack of pedagogical content knowledge among Geography teachers, which affects their ability to teach GIS effectively. The result of these constraints is that through PBGIS learners are learning about GIS rather than with GIS (Breetzke et al. 2011; DeMers et al. 2021; Whyatt et al. 2023) such as by using topographic and orthophoto maps to apply GIS concepts (Breetzke et al. 2011). However, the application of ICT can enable the display of audio-visual material, making it easier for learners to acquire knowledge.

ICT FOR TEACHING AND LEARNING

Integrating ICT into school education can help teachers modify their teaching methods in the classroom to improve learners' understanding and educational outcomes. With the help of ICT, teachers can perform better by utilising various tools and applications such as computers, projectors, cellphones, networks, artificial intelligence, digitisation, QGIS and ArcGIS (Ratheeswari 2018).

Several studies highlight how low-ICT school environments hinder the effective teaching of GIS, particularly in rural and under-resourced areas of South Africa. In the uMgungundlovu District of KwaZulu-Natal, only 27% of schools have computer labs and only 24% have access to GIS software, forcing most teachers to teach GIS as theory without any practical application (Mkhongi & Musakwa 2020). In such schools, teachers reporting low confidence and limited training in ICT-based GIS instruction (Mkhize 2023a). Learners in two KwaZulu-Natal high schools without digital resources had significantly lower digital literacy, directly impacting their ability to engage with GIS content (Mbalo et al. 2024). Township and rural schools in KwaZulu-Natal frequently face inadequate ICT infrastructure, unreliable internet, and frequent power outages, which hinder the meaningful integration of ICT into school subjects (Tigere & Netshitangani 2022). This highlights that despite GIS being a core curriculum requirement, ICT constraints limit its effective implementation in many South African schools, especially in rural areas.

THEORETICAL FRAMEWORK

This study employs the Technological Pedagogical Content Knowledge (TPACK) framework, developed by Mishra & Koehler (2006), which extends Shulman's (1986) Pedagogical Content Knowledge theory by emphasising the role of technology in effective teaching and learning. TPACK represents a teacher's understanding of how to teach subject-specific content using suitable pedagogical strategies and relevant technological tools. TPACK integrates technological, pedagogical, and content knowledge into a framework that explains how these domains interact in teaching (Saubern 2020; Santos & Castro 2021) (Figure 1). It is suitable for this study as it supports the exploration of how teachers use ICT to teach PBGIS, Geography content, and map skills in secondary schools.

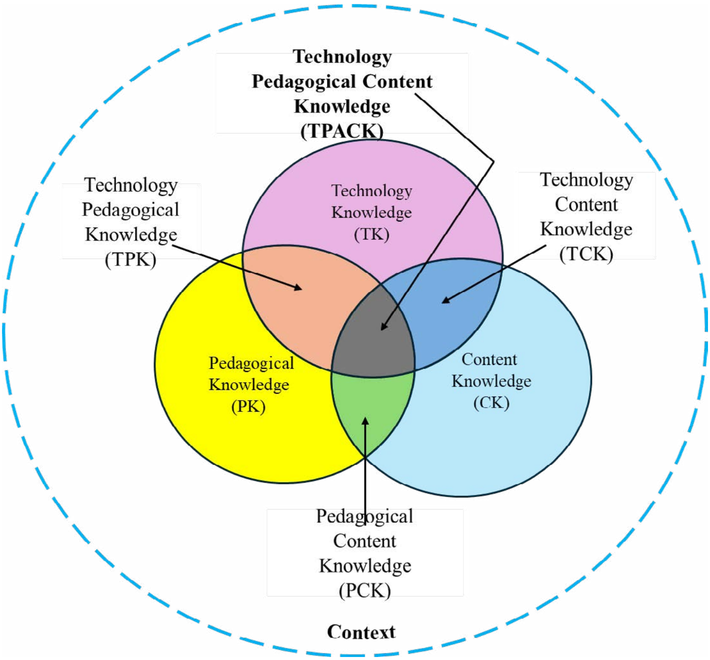

Figure 1. TPACK conceptual framework (modified after Santos & Castro 2021, p. 63).

In the TPACK framework, Technology Knowledge (TK) refers to the understanding and use of a range of tools, from pencils and paper to computers, projectors, and tablets. TK involves applying technology purposefully, recognising its impact on goals, and adapting to ongoing technological changes. TK supports the integration of visual tools, interactive maps, and GIS simulations using ICT, making PBGIS more engaging and accessible for learners. It reflects the teacher's ability to navigate resource constraints and educational objectives using available technology.

Content Knowledge (CK) refers to a teacher's understanding of the subject matter they teach. It requires familiarity with the content and an awareness of how knowledge varies across different subject areas (Fransson & Holmberg 2012). To effectively teach PBGIS when integrating ICT tools, teachers must grasp GIS concepts such as map reading, spatial analysis, data layering, buffering, and data integration. They must also understand the specific nature of GIS content and tailor their teaching strategies accordingly.

Pedagogical Knowledge (PK) refers to a teacher's understanding of teaching and learning methods, encompassing instructional strategies, educational goals, and the underlying values and purposes of education (Doukakis et al. 2021; Huang & Lajoie 2021; Schmid et al. 2021). Here, this includes exploring the teachers' skills to plan, deliver and assess PBGIS effectively.

Pedagogical Content Knowledge (PCK) integrates subject matter knowledge with effective teaching strategies. It varies across disciplines and supports teachers in delivering content in ways that enhance learner understanding (Harris & Hofer 2011; Santos & Castro 2021). In this study, PCK focuses on how teachers combined their understanding of GIS concepts with effective pedagogical approaches, and presenting GIS topics in ways that make them accessible to learners. PCK also focuses on how teachers structure GIS lessons, adapt explanations, and integrate paper-based tools and ICT to support learner understanding.

Technological Content Knowledge (TCK) refers to how technology can reshape the representation and learning of specific subject content, enabling teachers to engage learners more profoundly (Fargher 2018). In the context of GIS, TCK can consider how teachers use digital technologies such as interactive maps, spatial analysis tools and simulations to present concepts such as buffering, geocoding and thematic mapping. These tools provide dynamic visualisations that complement traditional PBGIS methods, offering new entry points for learner engagement.

METHODOLOGY

This study adopted a qualitative research design grounded in an interpretive paradigm, as the aim was to explore PBGIS teaching ICT integration in secondary schools, through the experiences of teachers. In this study, participants were six experienced Geography teachers (two from each of three schools) purposively sampled from selected secondary schools in the UGu district, KwaZulu-Natal Province, South Africa (Table 1).

Table 1. Demographic profile of participants.

Participant	Qualifications	Gender	Subject/s teaching	School Quantile	School setting	Teaching experience
GT1	BTTM & PGCE	Male	G & TRSM	1	R	14 years
GT2	BEd	Female	G	1	R	6 years
GT3	BEd	Male	G	1	R	9 years
GT4	BEd	Female	G	1	R	8 years
GT5	BEd	Male	G	1	R	16 years
GT6	BEd	Female	G & LSC	1	R	10 years

Key: GT = Geography Teacher, BEd = Bachelor of Education Degree, PGCE = Post Graduate Certificate in Education, BTTM = Bachelor of Travel Tourism Management, G = Geography, TRSM = Tourism, LSC = Life Sciences, R = rural school.

Semi-structured interviews (45–60 minutes duration) were conducted with the selected Geography teachers (GT). With consent, interviews were audio recorded. The transcribed recordings were analysed thematically following Braun & Clarke (2014). The study received ethics clearance from the University of KwaZulu-Natal (clearance number HSSREC/00004884/2022), with permission granted by the Department of Basic Education (DBE) (KwaZulu-Natal), school principals, and consent from research participants. Data are presented using pseudonyms for the schools and participants (GT1–GT6).

RESULTS AND DISCUSSION

Result of this study focus on three themes: using telematics to teach PBGIS, integrating QGIS into PBGIS teaching, and integrating ArcGIS into PBGIS teaching.

Using telematics to teach PBGIS

Participants taught PBGIS through utilising technologies such as computers, overhead projectors, and the internet in secondary school Geography classrooms. Evidence includes:

> *'I use the laptop and the overhead projector to display GIS notes I take from the internet. The projector displays clear images of GIS concepts, including remote sensing, resolution, spatial, and attribute data. While I explain, learners can refer to the displayed images and engage with the content more effectively, thereby understanding it better.' (GT1)*
>
> *'I used the overhead projector to display a PowerPoint presentation with GIS notes and images. Reviewing the notes, I also refer to images supporting the content.' (GT2)*
>
> *'I used a laptop to show learners a YouTube video of a teacher explaining the difference between spatial resolution and spectral resolution. As the YouTube video played, the learners observed and took notes.' (GT3)*

GT1 and GT2 indicate that they integrated telematics into teaching PBGIS, particularly using laptops and projectors to present digital content. These tools enabled teachers to display notes, diagrams, and maps more effectively, providing learners with clear visual information. ICT tools such as projectors, digital whiteboards, and multimedia presentations facilitate the integration of dynamic content, images, videos, animations, and interactive graphics into lessons (Das 2024). Telematics help to bridge the cognitive gap between theoretical GIS concepts and real-world applications by creating immersive, visually rich learning environments.

The use of telematics directly addresses barriers in PBGIS education including a lack of access to GIS labs and software, and the difficulty of engaging learners in rural or under-resourced schools (Arrasyid et al. 2019). Teachers could simulate GIS processes using low-cost and portable ICT tools without high-end infrastructure. However, Mkhongi & Musakwa (2020) observe that classroom ICT use in South Africa remains inconsistent and underutilised. GT1 and GT2 reflected on how the use of telematics facilitated curriculum delivery and helped overcome constraints associated with teaching PBGIS, making abstract spatial concepts more tangible and accessible to learners.

Technology Knowledge (TK) in TPACK focuses on the knowledge about various technologies, here including low-tech technologies such as pencil and paper to digital technologies such as computers, internet connection, monitors for projection, printers, projectors and scanners (Fransson & Holmberg 2012). For TK, users need to understand information technology well enough to apply it (Santos & Castro 2021), meaning that the Geography teachers need to have the skills to use different technologies to support effective PBGIS teaching and learning. The data showed that Geography teachers saw ICT as advantageous because it allowed for the retrieval of images from the internet:

> *'I expose learners to different pictures that show differences in resolution. When the video ends, I ask learners questions based on the video they watched about resolution. Learners usually become active and answer questions. Their response indicates to me whether they have understood or not.' (GT3)*

Visual materials can help learners understand concepts such as digital image resolution, engage with content interactively, and improve knowledge retention (Dahlan et al. 2023). Active learner engagement can be facilitated by using materials learners can refer to (such as digital images) for observation, analysis, and interpretation, thereby developing responses. TPACK, on the other hand, helps teachers understand the interplay between technology, pedagogy, and content knowledge to design effective and meaningful learning experiences, particularly when using ICT to teach with visuals (Koh & Chai 2016; Mahlo et al. 2024). Hence, Geography teachers should understand the links between ICT and specific pedagogical strategies for teaching PBGIS content knowledge.

QGIS integration to PBGIS teaching

The participants stated that previously they relied on maps, textbooks and telematics to teach PBGIS. The participants acknowledged the role of these resources in making PBGIS understandable to learners. However, GT4 explained how they have begun incorporating QGIS into their lessons:

> *'Over the past year, I have primarily relied on paper, textbooks, and telematics, which have helped me make GIS more relevant to learners. This year, I have started using a GIS app called QGIS to create more practical examples for them, showing how they must apply these concepts in GIS. I do understand that it is a paper-based GIS, but it is a computer-based system. Therefore, learners must understand how to apply these concepts in teaching GIS.' (GT4)*

Here, QGIS was used to demonstrate how GIS concepts can be applied using computer-based tools, highlighting a shift from theoretical teaching to a more practical, learner-centred approach. GT4 described how QGIS enhanced practicality and engagement for learners who were otherwise struggling to visualise abstract GIS concepts. Access to QGIS in GT4's school was made possible through self-initiated efforts, supported by peer collaboration; GT4 received the software from a Geography teacher at a neighbouring school. This informal, teacher-driven network demonstrates the potential for grassroots innovation in GIS education, especially where formal support structures are limited.

QGIS (previously Quantum GIS) is a free, open-source, cross-platform desktop GIS application licensed under the GNU General Public License (Khan & Mohiuddin 2018). It enables the collection, editing, and spatial analysis of geospatial data. The use of QGIS in schools enables learners to interact with real-world spatial data, thereby developing practical learning experiences that can help conceptual understanding and skills development (Aurellia et al. 2023). GT4's use of QGIS reflects how, when empowered and supported, teachers can to integrate technology into PBGIS instruction. This aligns with the broader goals of the TPACK framework, which supports the blending of content, pedagogy, and technology to enhance learning outcomes.

Results also showed that the Geography teachers strongly recommended integrating GIS applications such as QGIS and ArcGIS into PBGIS teaching in secondary schools. GT5 said:

> *'I would be happy if we could have access to GIS apps in schools so that our learners can visualise what we are referring to when we teach concepts such as data layering, data integration, or buffering. Teaching these highly technical concepts using topographic maps and orthophoto maps is insufficient. It makes our learners wonder what it would be like to use the actual app to explore these concepts.' (GT5)*
>
> *'I know the kind of GIS we are teaching learners right now is typically done on maps, but incorporating apps might enhance our explanations of GIS concepts to learners. Making learners imagine how they would apply a concept on computers might not be effective because they may not think in the same way.' (GT6)*

These reflections highlight that GIS concepts such as data layering, integration and buffering cannot be effectively taught solely through theory. GT5 recognised that learners are more likely to grasp these abstract ideas when engaged in interactive, application-based learning. GIS applications such as QGIS can enable teachers to design interactive and practical GIS lessons using real-world data (Khan & Mohiuddin 2018; Firomumwe & Gamira 2021). Its ease of use and versatility make it particularly suitable for secondary school environments, where learners and teachers may be new to GIS technologies.

Anchoring this integration within the TPACK framework strengthens its pedagogical value. Through TPACK, teachers are equipped to meaningfully combine their content knowledge (e.g. GIS concepts), pedagogical strategies (e.g. inquiry-based or experiential learning), and technological tools (e.g. QGIS, GPS, DIVA-GIS, ArcGIS). This enables them to design lessons that cover the curriculum and engage learners in hands-on, real-world spatial thinking. TPACK supports teachers in selecting appropriate tools that enhance, rather than distract from, learning, a critical consideration when teaching data-intensive GIS topics (Curtis 2019). Furthermore, the use of QGIS and ArcGIS also reinforces broader digital competencies required across the Geography curriculum. Topics such as remote sensing and spatial data analysis require familiarity with ICT and a shift in teaching methodology toward digitally mediated, learner-centred approaches. In a modern Geography classroom, ICT tools are key resources for effectively teaching geospatial content. Without such tools, teaching and learning risk remaining abstract, detached, and insufficiently aligned with the realities of contemporary geographic practice.

ArcGIS integration into PBGIS teaching

ArcGIS is another computer-based application that a Geography teacher recommended for teaching PBGIS in secondary schools. GT2 stated:

> *'Teaching GIS would be much easier if we had software applications like ArcGIS. Teachers should expose learners to more practical experiences with GIS rather than just theory. I know that these GIS apps are available at the university level to teach students about GIS. At the institution where I studied, I was taught using ArcGIS, where GIS concepts were applied using computers. For learners at the school level, it is more about teaching and raising awareness of scenarios rather than taking them through the actual application of GIS and how they can find information by themselves using data provided in a GIS system.' (GT2)*

Exposure to ArcGIS during university training significantly influenced the perception of GT2 to the value of GIS in the classroom. However, the cost and licensing of proprietary platforms like ArcGIS can pose significant barriers for under-resourced schools (Breetzke et al. 2011). In contrast, QGIS is a free and open-source alternative that offers GIS functionality without the financial constraints of commercial software (Ratheeswari 2018). Its accessibility makes it a viable option for implementation across the South African secondary education system. Therefore, while teacher training institutions may continue to use ArcGIS, integrating QGIS into classroom instruction may be more equitable and sustainable. Future training and curriculum development should consider the balance between industry alignment and accessibility, to ensure that all learners benefit from hands-on GIS learning, regardless of their school's resources.

The results also showed that struggling learners do not see how PBGIS fits into GIS, as it is paper-based rather than computer-based. GT2 said:

> *'Some learners try to understand the concept of GIS as paper-based and be able to do it, but you still find learners who cannot see GIS as fitting into Geography because it is only something that links to something, but the actual application is not there for them. So, some may struggle with that. If there had been a proper application, it would have been much better.' (GT2)*

GIS enables learners to work with real-world spatial data, relevant in various fields such as urban planning, environmental science, transportation, and emergency management (Kerski 2023). Teachers can incorporate case studies and practical examples into lessons, helping learners see the relevance of GIS in addressing real-world problems. It can also allow for advanced map creation and spatial data visualisation, which helps learners understand complex geographic patterns and relationships (Kerski 2023). Using this approach, teachers can demonstrate how to visualise data, interpret spatial patterns, and communicate results effectively through interactive web maps. TPACK helps teachers consider the intersection of technology, pedagogy, and content knowledge to ensure that GIS is used to enhance learning experiences and spatial concepts (Hammond et al. 2018). By following the TPACK framework, teachers can effectively leverage such tools to make GIS education more engaging, accessible and relevant to learners.

CONCLUSIONS AND RECOMMENDATIONS

This study concludes that Geography teachers find the traditional approach to teaching GIS through topographic and orthophoto maps to be insufficient. Instead, they advocate integrating ICT into teaching PBGIS to enhance learners' understanding of spatial concepts. Teachers acknowledge that while telematics such as computers, laptops, projectors, and internet access improve lesson delivery by supporting visual and interactive content, these do not provide learners with the practical experience necessary to understand the application of GIS. The Geography teachers recommend incorporating applications such as QGIS and ArcGIS into classroom practice. These tools can enable learners to engage actively with spatial data, apply GIS concepts to real-life problems, and develop digital skills. GT2 observed: 'Some learners try to understand the concept of GIS as paper-based and be able to do it, but you still find learners who cannot see GIS as fitting into Geography… I think if there were a proper application, it would have been much better.' This statement underscores the limitations of a theory-only PGGIS approach and reinforces the importance of practical applications in achieving meaningful learning outcomes.

Recommendations from this study include a phased, collaborative rollout of telematics and GIS software in South African secondary schools, supported by partnerships among the DBE, geospatial and education technology industries, teacher training institutions, NGOs, and universities. Previous studies also emphasise the need for enhanced collaboration between the DBE and higher education institutions to provide targeted GIS training and better support for teachers (Mkhongi & Musakwa 2020; Manik 2022). These partnerships are essential for capacitating teachers and ensuring sustainable implementation. Future research could explore how GIS software enhances learners' spatial comprehension and skills, identify barriers to integration across diverse school contexts, develop GIS-focused teacher-training programmes, and assess the impacts of blended ICT and GIS teaching strategies on engagement and achievement in Geography.

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