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Proceedings of the International Conference on Teaching, Learning and Education
Vol. 2, Issue. 1, 2025, pp. 40-58
DOI: https://doi.org/10.33422/ictle.v2i1.1135

ISSN: 3030-122X online

Adopting Problem-Based Learning to enhance Paper-Based GIS teaching in a rural learning ecology

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Abstract

Paper-based GIS (PBGIS) teaching in schools has been a topic of considerable debate in the Geography literature. This article contributes to the discussion by offering a new perspective on teaching PBGIS in a rural learning ecology, specifically through Problem-Based Learning (PBL). Six Geography teachers from four schools in the UGU district, KwaZulu-Natal Province, South Africa, were selected to gain insights regarding how they adopted PBL to enhance PBGIS teaching in a rural learning ecology. The PBL teaching method involves complex real-world problems used as vehicles to promote learners' learning of concepts and principles as opposed to the direct presentation of facts and concepts. The Technology Pedagogical Content Knowledge (TPACK) framework underpins this article, with its core premise being the technology knowledge a teacher requires for effective teaching and learning. TPACK recognises the integration of technology knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK) to create a framework that encompasses specialised, applied, and situated knowledge, helping us understand how different aspects of knowledge interact and become integrated. Geography teachers should be knowledgeable about integrating PBGIS, PBL, and Geography knowledge to enhance PBGIS teaching in a rural learning ecology. A qualitative research approach, Participatory Action Research (PAR), was employed, along with interviews and video-recorded lesson observations (VRLs), for this inquiry. The findings showed that using PBL to teach PBGIS engages learners in problem-based, real-life scenarios and promotes collaboration and critical thinking skills in learners to solve real-life problems. The article recommends that education stakeholders adopt PBL to enhance PBGIS teaching in rural areas. It highlights the need for teacher training in PBL methods and calls for policymakers to provide accessible, high-quality PBGIS materials.

Keywords: Critical thinking, Geographic Information Systems, Paper-based GIS, Problem-based Learning, real-life problems, rural learning ecology

1. Introduction

Geographic Information Systems (GIS) have become an essential component of modern geography education, offering learners powerful tools to interpret spatial data, analyse patterns, and make informed decisions about the world around them. However, in many rural learning ecologies, particularly in under-resourced settings, schools face significant barriers to implementing digital GIS technologies due to limited infrastructure, inadequate funding, and a lack of teacher training (Mkhize et al., 2023; Olatoye & Fru, 2024). These constraints often prevent learners from accessing the full benefits of GIS-based learning, creating a need for alternative approaches that can simulate GIS thinking and skills using available resources. In response to these challenges, Paper-Based GIS (PBGIS) has emerged as a practical alternative, allowing teachers to teach spatial concepts and analytical skills using printed maps, atlases, and layered data (Mkhize, 2023). While this method lacks the interactivity of digital tools, it still provides learners with opportunities to engage in spatial reasoning and develop foundational geographic competencies. However, the effectiveness of PBGIS depends mainly on the pedagogical approaches used to deliver it.

It has almost been two decades since the Department of Basic Education (DBE) introduced PBGIS in South African secondary schools. However, the teaching of PBGIS in secondary schools still faces numerous challenges, and this has been a topic of considerable debate in the Geography literature. The literature shows that in schools, there is a lack of teacher professional training in PBGIS, a lack of Information and Communication Technology (ICT) infrastructure, a lack of resources such as maps, and unclear guidelines regarding pedagogical approaches to teaching PBGIS schools (Fleischmann & Van der Westhuizen, 2017; Mkhize et al., 2023; Hlatywayo & Manik, 2022; Tarisayi & Zondi, 2020). This article contributes to the debate by offering a new perspective on teaching PBGIS, specifically problem-based learning (PBL).

PBL, a learner-centred pedagogical approach, encourages learners to explore real-world problems collaboratively, fostering critical thinking, inquiry, and independent knowledge construction (Güneş et al., 2020). Integrating PBL with PBGIS teaching can enhance learner engagement and deepen understanding of geographic content, especially in rural classrooms where access to technology is limited (Orfan et al., 2021). By framing geographic challenges in meaningful, real-life scenarios, PBL can help bridge the gap between content and context, making geography more relevant and accessible to learners. This study explored how adopting PBL can enhance the teaching of PBGIS in a rural learning ecology. It focuses on how teachers design and implement problem-based activities, how learners respond to this approach, and how teachers foster spatial thinking without the use of digital GIS tools. The research aims to contribute to the development of context-appropriate pedagogical approaches that empower both teachers and learners in under-resourced environments, supporting equity and innovation in geography education. The article is arranged as follows: literature review, conceptual framework, methodology, findings and discussion, recommendations, and conclusion. The literature review will tap into the existing body of knowledge about the phenomenon under discussion; the TPACK conceptual framework will provide a structured way to understand and address the research problem; the research methodology will outline how we conducted the research; and the findings will serve as the foundation for data interpretation and discussion of the implications of the study.

2. Literature review

Several studies have been conducted on the use of PBL to teach GIS in secondary schools. Tan (2021) notes that learning with PBL-GIS pedagogy can lead to higher-order learning outcomes. France and Haigh (2018) note that PBL facilitates active learning to produce critically self-aware, self-directed practitioners. Hence, PBL has a positive impact on learner confidence, and its learner-focused approach fosters a deeper understanding of the subject matter. PBL is an effective teaching strategy for Geography at K–12 levels (Permadi et al., 2022). In another study, Osborne et al. (2020) examined the integration of geospatial technology in K-12 education. The findings suggest that integrating geospatial technology into North Carolina K–12 classrooms enables teachers and learners to expand their geographic knowledge through interactive, innovative problem-solving techniques that utilise common tools. The findings also suggested that problem-based activities are more effective than textbook-based exercises. In a problem-based learning classroom, theoretical foundations and the real world of problems are understood as constitutive of one another, rather than theory being prioritised over the real world of experience (Osborne-Crowley, 2020).

In a different study, Schlemper et al. (2019) conducted a study titled 'Teaching Spatial Thinking and Geospatial Technologies Through Citizen Mapping and Problem-Based Inquiry in Grades 7-12'. The study aimed to introduce learners in grades 7 through 12 to spatial thinking and geospatial technologies in the context of community challenges. Learner-suggested problem-based topics included parks and community gardens, crime, housing, and youth employment opportunities. The findings suggest that the PBL approach helped learners address the issue of environmental injustice related to the need for a fairer distribution of services across all districts in the city (Schlemper et al., 2019). The findings also suggested that learners' knowledge of both skills and their communities was enhanced through a problem-based, authentic learning experience that focused on real-world topics they cared about while using citizen mapping as a tool that fosters an open inquiry approach to learning.

In another study conducted in Indonesia, Utaya et al. (2020) uncovered geospatial technology (GST) gaps and patterns (geospatial technology) knowledge transformation among pre-service and experienced Geography teachers using GST as an educational tool based on the TPACK conceptual framework (Collins & Mitchell, 2019; Curtis, 2019; Hammond et al., 2018; Mishra, 2019). They argue that GST integration into material content is implemented as a basis for thinking and acting to solve problems and make decisions, especially in geographic contexts. The results revealed a knowledge gap in GST between pre-service and experienced Geography teachers. The low implementation ability of experienced teachers means that GST is not an optimal pedagogical tool for Geography learning within the TPACK framework. Therefore, the TPACK framework needs to be practised in continuous Geography learning and changing the paradigm of 'learning from GST' by learning with GST to strengthen the curriculum.

In South Africa, few studies have explored the use of PBL in teaching PBGIS in South African schools. Mzuza and Van der Westhuizen (2019) emphasise that teaching with GIS is of major importance and cannot be overlooked, as it is a valuable tool in helping learners acquire a range of skills. The article analysed some skills developed in teaching and learning through GIS and examined the significance of the skills gained. According to the results, teaching through GIS distinctively indicates the development of problem-solving and spatial thinking skills, which can also foster self-directed learning. Problem-solving skills are essential skills that should be emphasised in 21st-century learning. Fadli (2020) notes that problem-solving skills involve the capability to identify, plan, evaluate, and find solutions to determine new answers. Thus, PBL as a 21st-century learning method may enable Geography teachers to engage learners in collaborative learning to identify problems, plan, evaluate, and formulate solutions to the problem. PBL is a learner-centred educational method that aims to improve problem-solving skills through self-directed learning and teamwork (Ali, 2019). PBL helps learners acquire various generic skills, such as communication, negotiation, and problem-solving (Orfan et al., 2021). Hence, developing lessons that use BPL to teach PBGIS in a rural learning ecology is essential.

In another study, Tarisayi and Zondi (2020) argue that in South Africa, many studies provide a teacher's perspective on GIS implementation in schools while neglecting the learner's perspective. Therefore, their study explored a learner's perspective on implementing GIS in selected schools in the KwaZulu-Natal province. They suggested that learners lacked a fundamental knowledge of GIS and that GIS was not being taught properly. Therefore, PBL is one of the most effective teaching methods for improving the quality of learning in PBGIS in South African secondary schools (Orfan et al., 2021). PBL enables learners to develop critical thinking, problem-solving, decision-making, and creative thinking. Additionally, PBL allows learners to seek self-directed learning resources and be more involved in learning and practising.

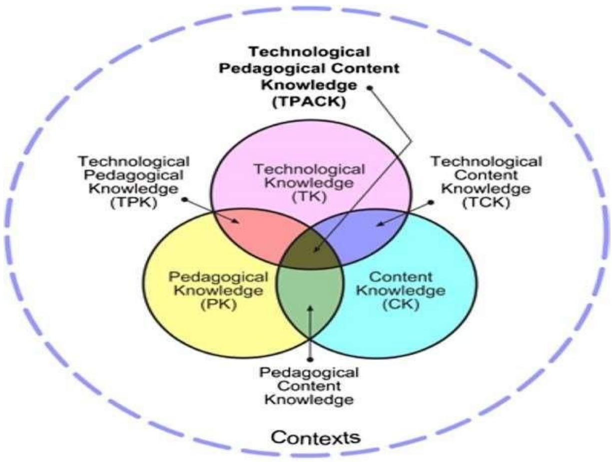
While previous studies have contributed valuable insights into applying PBL in teaching GIS, most of this research has been conducted in urban or well-resourced secondary schools, where access to digital GIS tools, such as computers, mapping software, and internet connectivity, is relatively common. These studies have shown that PBL enhances learners' engagement, critical thinking, and ability to apply spatial knowledge to real-world problems. However, they have largely overlooked the contextual challenges faced by rural schools, where technological infrastructure is often lacking or inconsistent. In many rural learning ecologies, particularly in the Global South, teachers do not have access to digital GIS platforms and must rely on PBGIS resources such as printed maps, atlases, spatial overlays, and locally gathered data (Mkhize, 2023; Olatoye & Fru, 2024). Large class sizes and rigid timetables make it difficult for teachers to facilitate group-based, inquiry-driven activities, which require more preparation time and individualised support. Many teachers may lack the training, confidence, or experience to design and implement PBL effectively, especially when it involves specialised skills like GIS or digital mapping (McKenzie et al., 2022). National assessments in South Africa often emphasise content recall over inquiry, problem-solving, or application (Chetty, 2016). This disconnect can discourage teachers from adopting PBL, as it may not align with exam-focused outcomes. The current CAPS curriculum, while open to innovation, is still prescriptive in many areas. Teachers may feel constrained by strict curriculum pacing and a lack of institutional encouragement for PBL experimentation (Tryon, 2023).

The aforementioned presents a significant pedagogical gap, as the benefits of GIS education may be limited when conventional teaching methods fail to engage learners or simulate real-world spatial analysis effectively. Therefore, this study is distinctive and original in that it shifts the focus from digital GIS teaching to PBGIS learning in under-resourced, rural settings and examines how PBL can be used as a transformative pedagogical approach in these contexts. It argues that geography teachers can meaningfully implement PBL to teach key GIS concepts, such as map interpretation, spatial reasoning, and geographic decision-making, even without access to digital tools. In light of this, the study aimed to adopt and evaluate PBL as a method to enhance the teaching and learning of PBGIS in rural learning ecologies. By exploring how PBL can empower teachers and learners to engage with real-life spatial problems using available materials, this research contributes to more inclusive, equitable, and contextually relevant geography education.

3. TPACK conceptual framework

TPACK serves as the underlying conceptual framework for the study. TPACK evolved from Shulman's (1986) theory of PCK and focused on the need for teachers to skillfully demonstrate their ability to integrate technology within the constructs of content and pedagogical domains. Mishra and Koehler (2006) describe TPACK as a teacher's intuitive ability to teach subject-specific content using appropriate pedagogical methods and selected technologies. Hence, TPACK enabled geography teachers to engage learners in PBGIS activities through PBL by providing them with problem-based or scenario-based questions to answer, utilising GIS concepts on topographic and orthophoto maps. Teachers base the scenarios on real-world experiences, encouraging learners to collaborate and develop solutions to problems, thereby constructing knowledge independently.

Figure 1: TPACK conceptual framework



Source: Santos & Castro (2021, p 63)

The TPACK framework is essential for understanding how teachers integrate technology, pedagogy, and content knowledge in meaningful ways, particularly in settings with limited digital infrastructure, such as rural learning ecologies. Technological Knowledge (TK): Although this study's setting may lack advanced digital GIS tools, paper-based GIS still requires technological knowledge. TPACK helped explain how teachers utilise low-tech resources, such as maps and overlays, to simulate GIS thinking (Asim et al., 2022). Pedagogical Knowledge (PK): PBL is a learner-centred approach, and TPACK helped examine how teachers design GIS-based activities without digital tools. It also highlights how pedagogy adapts to engage learners in rural, resource-limited settings (Ofosu-Asare, 2024). Content Knowledge (CK): This study focuses on GIS content, and TPACK ensures it's taught alongside suitable pedagogy and available (paper-based) technology (Schoeman & Chidzungu, 2025). It helps analyse how teachers support spatial thinking and data interpretation without software.

Technological Pedagogical Knowledge (TPK): Helped explain how teachers choose appropriate paper-based tools to support inquiry and problem-solving (Galanti et al., 2021). Technological Content Knowledge (TCK): Framed how teachers understood GIS concepts through non-digital technologies (Ofosu-Asare, 2024). Pedagogical Content Knowledge (PCK) highlights how teachers tailor PBL approaches specifically for teaching GIS (Schoeman & Chidzungu, 2025). TPACK (integrated knowledge): Ultimately, this study demonstrates how teachers effectively blend all three knowledge domains to teach GIS using problem-based learning in a rural context.

4. Methodology

This study adopted a qualitative research design, guided by the critical paradigm. Both the qualitative approach and the critical paradigm were appropriate for this research, which aimed to explore how PBL could be adopted to enhance PBGIS teaching in a rural learning ecology. Rooted in critical theory, the critical paradigm is based on the belief that research should not only interpret societal behaviours but also contribute to transforming them towards greater equity and justice. As Cohen et al. (2007, p. 26) explain, the purpose of critical research is the "emancipation of individuals and groups in an egalitarian society." In this study, the researchers used the critical paradigm to examine how adopting PBL could help improve the teaching and learning of PBGIS in under-resourced, rural contexts, with the goal of challenging existing limitations and promoting transformative educational practices that support both teachers and learners.

This study employed a Participatory Action Research (PAR) methodology to adopt PBL as a means to enhance PBGIS teaching in a rural learning ecology. PAR is a transformative research approach that aims to understand and improve the world through active change (Baum et al., 2006; Brydon-Miller et al., 2020). At its core, PAR involves collective, self-reflective inquiry, where researchers and participants collaboratively explore and enhance their practices within their real-world contexts. Collaboration in this study involved activities related to identifying the current pedagogical approaches to teaching PBGIS in a rural learning ecology and exploring the (in)effectiveness of these approaches to improve the pedagogical strategies. Collaboration in this study involved six phases of PAR: phase one: initial planning; phase two: acting; phase three: observing and reflecting; phase four: planning intervention; phase five: acting; and phase six: observing and reflecting. These are aligned with the PAR cycle (Zuber-Skerritt, 1995, p. 13). In the first phase of data generation, we used one-on-one semi-structured interviews with ten co-researchers, one session per co-researcher. Phase two of the study involved ten co-researchers conducting the first Video-recorded lessons (VRLs) while teaching PBGIS, aimed at exploring current pedagogical approaches used by geography teachers in a rural learning context. Phase three involved focus group discussions (FGDs) at some rural schools near iZingolweni, where researchers reviewed ten VRLs to identify and evaluate the effectiveness of pedagogical approaches used to teach PBGIS in a rural context. Santos et al. (2020) note that FGDs are a type of group interview in which the researcher poses targeted questions designed to elicit collective views on a specific topic. According to Edwards (2020) and Rodriguez (2021), it is essential to decide what to focus on in each observation.

Phase four involved a second focus group discussion (FGD) session where researchers identified problem-based learning (PBL) and visualisation as suitable pedagogical approaches for teaching PBGIS in a rural context and collaboratively planned lessons using these methods. Phase five involved co-researchers conducting a second set of VRLs to teach PBGIS using the newly adopted pedagogical approaches. The VRLs were conducted for approximately forty-five minutes to one hour. Phase six involved the researchers engaging in the third FGD session, during which they observed and reflected on the second set of six VRLs by discussing the teaching approaches identified. According to Edwards (2020) and Rodriguez (2021), it is important to decide what to focus on in each observation. During the FGD session, the researchers aimed to identify and discuss how teachers adopted pedagogical approaches in the classroom and how effective or ineffective they were in improving PBGIS teaching within a rural learning ecology. Audio-recording and video-recording devices were used to record the interviews and teach the PBGIS lessons.

Purposive sampling was adopted as the sampling strategy to recruit participants. Purposive sampling is a representative and non-random approach; the selected participants possess the necessary information (Rahi, 2017). Purposive sampling enabled me to choose deliberately five geography teachers who were actively involved in teaching PBGIS, particularly in rural, resource-constrained environments where digital technologies may not be readily available. These teachers were best positioned to provide informed insights into how PBL can be applied to enhance the teaching of PBGIS. Therefore, purposive sampling supported the depth and relevance of data collection, ensuring that the findings were grounded in the realities of the rural learning ecology. It also aligns well with the research's qualitative, critical, and participatory nature, in which the focus was on deep understanding rather than generalisability.

The thematic data analysis approach was used to see and make sense of the collective or shared meanings and experiences indicated by the dataset. The data were analysed using both deductive and inductive approaches. Clarke and Braun's thematic analysis of a six-phase process was adopted for familiarisation, generating initial codes, searching for themes, reviewing potential themes, defining and naming themes, and producing the report of the collected data (Braun & Clarke, 2019). Ethical considerations are important in qualitative research as this approach often intrudes on participants' lives (Flick, 2018). The principles of research ethics require researchers to avoid harming participants involved in the process by respecting and considering their needs and interests (Khan, 2014). Research permission was requested from the DBE, school principals, and research participants to interview Geography teachers in two selected schools within the Province of KwaZulu-Natal. Ethical clearance was granted to conduct this research. The confidentiality of the participants was ensured by using pseudonyms for the schools and participants to prevent the disclosure of individual identities (Bertram & Christiansen, 2014). Deductive and inductive thematic analysis approaches were used to address credibility (Braun & Clarke, 2019). The conclusions were drawn only from the participants of this study, and the findings were not generalised to other contexts (Bertram & Christiansen, 2014). Peer debriefing, member checking, and support were solicited from colleagues to check the interpretation of the data (critical peer checks) (Rule & John, 2011). Verification of the accuracy of the reported information about participants was requested from the participants (Rule & John, 2011). Audio and video recording devices were used to capture the interviews and lessons. This enabled the production of accurate transcripts (Bertram &Christiansen, 2014).

5. Findings and discussions

The findings indicate that the co-researchers used PBL to engage learners in problem-solving activities centred around scenarios formulated using geographical content knowledge. Below are reflections from the FGD and VRL observations detailing how PBL was utilised to teach PBGIS in this context. GT9 reflects:

> "*The problem-based method was used when learners were presented with the problem, which they had to solve in the Gqeberha map, where they had to deal with pollution in rivers in Gqeberha.*" *(FGD)* **GT9**

The VRL observation extract below illustrates the classroom experience of GT9 in adopting PBL for teaching PBGIS in a rural learning ecology. GT9 VRL observation shows the following:

Teacher: *Let us say you are an environmental scientist tasked with dealing with pollution around the area of Gqeberha that is affecting our rivers. How would you use GIS to address the issue of pollution in the rivers in the mapped area? You have five minutes to discuss, two minutes to consolidate, and three minutes to present how you will use different GIS tools to address pollution.*

All learners: *(Learners discuss in groups.)*

Teacher: *(moves around checking progress, guides learners in their groups).*

One group member: *(presents to the whole classroom). If I were an environmental scientist, I would use two types of data tools. I will start by using buffering, which will prevent industrial waste from entering rivers. As you can see, the Gqeberha area is full of industries. This process will also prevent people from informal settlements from building their houses near the rivers. As we know, informal settlements are full of pollution. As shown in Blocks two and three, buildings are seen as low-cost housing. So, we can also assume that the area consists of informal settlements. I will also use another tool, which is data sharing. On the Internet, I will educate people about how to reduce water pollution and inspire others.*

The extracts above by GT9 show that the co-researcher presented learners with the problem of pollution in the Gqeberha area, affecting the rivers where they had to work in groups to solve it. According to Peacock (2018), PBL focuses on problem-solving, self-directed learning, team participation, and cooperation. Pedagogical content knowledge (PCK) in TPACK suggests that the pedagogical approaches teachers use to teach should encourage a high degree of learner participation, contribution, and production (Santos & Castro, 2021). Using PBL, group work enabled learners to interact with each other, sharing multiple ideas about solutions they could adopt to address pollution affecting rivers in the Gqeberha area. By using local environmental issues like river pollution, the lesson aligns with the Curriculum Assessment Policy Statement's (CAPS) emphasis on real-life application and promotes curriculum responsiveness to local contexts (DBE, 2013). This supports calls for greater integration of local content in teaching materials and encourages teachers to adapt content to learners' lived experiences, especially in under-resourced or rural settings.

In solving the problem, the abstract above by GT9 indicates that the co-researcher provided clear instructions regarding the PBGIS activity question a breakdown of the steps involved in executing the task, and highlighted that the solutions would be presented in the classroom upon completion. Güneş et al. (2020) note that the PBL method encourages learners to collaboratively solve problems in PBGIS by first identifying the general steps to solve the problem and then determining the PBGIS knowledge needed to process the data to arrive at solutions. The clear instructions the co-researcher provided to learners on what was expected guided them in the aspects to discuss during their interactions, addressing the problem of pollution affecting the rivers in the Gqeberha area. The provision of clear instructions minimised confusion and reduced errors that learners committed while executing the task.

The VRL observation extract above by GT9 also shows one group member presenting solutions to pollution affecting rivers in the Gqeberha area. The solutions are centred around the following geography and GIS concepts: pollution, buffering, industries, informal settlements, low-cost housing, rivers, and data sharing. Schlemper (2019) notes that PBL encourages learners to employ critical thinking and engage their curiosity in solving real-world problems during group discussions, thereby promoting inquiry and interest in the subject matter. TPACK reveals that teachers use pedagogical practices that enable learners to demonstrate creativity and innovation, strong communication and collaboration skills, critical thinking and problem-solving abilities, multiple literacies, and technology expertise when teaching PBGIS (Huang & Lajoie, 2021). Thus, the use of geographic concepts in the learners' solutions mentioned above suggests that learners engaged in a comprehensive group discussion, employing sound geographic and PBGIS content knowledge (CK) to think critically and work collaboratively, consolidating and presenting their ideas to the rest of the classroom.

The findings also indicate that PBL was adopted to identify an environmental problem on the map in a particular block and develop solutions as GIS specialists. The comment and VRL observation extracts below by GT1 indicate the following:

> "*I used problem-based learning, where learners became specialists who had to come up with the causes and solutions to the presented problem. Learners had to identify the environmental problem that was shown in the image. Having identified the environmental problem, we looked at decision-making because learners had to look at the cause as per the discussions.*" *(FGD)* **GT1**

The GT1 VRL observation extract below corroborates with the above extract in the following way:

Teacher: *We have an environmental issue in block C2 on the topographic map on page sixteen. First question: Identify the environmental issues depicted in the photographs. What problem do we have in block C2?*

One group member: *The problem depicted in block C2 is soil erosion.*

Teacher: *Now, we can solve our problem. 3.3.4. As a GIS specialist, what solution will you recommend to the authorities to overcome the environmental issue shown in the photo? How will you now overcome the issue of erosion? Have a discussion.*

All learners: *(discuss).*

Teacher: *Ntando.*

One group member: *He must sell the animals.*

Teacher: *Guys, the first thing he should do is to stop overgrazing. How do you stop overgrazing? There are many ways he should stop overgrazing.*

All learners: *(silent).*

Teacher: *Instead of taking all the animals and putting them in a small area, he should let them roam on his farm because keeping them in a small area leads to erosion.*

The extracts above by GT1 show that the co-researcher adopted PBL to instruct learners to identify the environmental issues depicted in block C2 on the topographic map. Learners identified erosion as a problem. Identifying this environmental issue assessed learners' map-reading skills, which involve navigating the map efficiently and locating and interpreting key features. According to Steggink (2021), using PBL to teach PBGIS helps develop learners' spatial reasoning, spatial problem-solving, spatial thinking, and computing skills. Naxweka and Wilmot (2019) explain how the TPACK conceptual framework reveals that PCK in mapwork and PBGIS refers to a teacher's proficiency in presenting geographic concepts through various maps to promote learners' spatial thinking skills. Therefore, identifying erosion as an environmental issue requires learners to understand how to read the topographic map patterns that provide clues about the shape and characteristics of the land that promote erosion. For CAPS, this enhances curriculum guidance to emphasise spatial literacy not just as a technical skill but as a tool for environmental analysis and civic engagement (DBE, 2013). GT1's approach moves beyond memorisation to assess learners' application of knowledge, a cornerstone of 21st-century education. This supports a policy push toward competency-based assessment models that reward higher-order thinking, as outlined in the DBE's CAPS revisions. This highlights the need for ongoing professional development that equips teachers to implement inquiry-based methods, especially in geography and the social sciences.

The VRL observation extract above by GT1 reveals that the co-researcher asked learners about the solutions they would recommend to the authorities to address the environmental issue of erosion, as shown in block C2 on the topographic map. Xiang and Liu (2019) note that PBL enables teachers to engage learners in PBGIS activities, which utilise GIS as a powerful problem-solving tool, thereby creating learning environments that stimulate active exploration and problem-solving in an interactive and integrated manner. Koehler and Mishra (2005) state that TPACK refers to the knowledge that teachers require to integrate content, pedagogy, and technology for effective teaching and learning. Hence, the geography teacher enabled learners to critically assess the erosion problem in block C2 by considering various perspectives through interaction and using GIS as a tool to develop potential solutions based on evidence and logic.

The VRL observation extract above by GT1 indicates that the co-researcher discovered that learners mistakenly stated that the farmer must sell livestock to stop overgrazing. In line with GT1, Schlemper et al. (2019) note that PBL enables teachers to allocate more time to monitoring learners' engagement and facilitating group discussions, thereby promoting effective teaching and learning. Consequently, the geography teacher attempted to guide the learners but realised they were still struggling and ultimately provided them with the correct answer. Allowing learners to take ownership of their learning by having them develop solutions independently enabled the teacher to quickly identify strengths and areas needing improvement, which reinforced learning and facilitated real-time adjustments. Hill and Uribe-Florez (2020) reveal that TPACK suggests using PBL to teach PBGIS, enabling teachers to monitor responses, thereby obtaining useful data about learners' learning and providing more immediate feedback.

The findings show that the co-researcher adopted PBL to introduce learners to the concept of buffering. Below is a reflection from FGD and VRL observations detailing how buffering reduced flooding that might have affected a hotel. GT7 reflects:

> "*All right, problem-based learning. When I was doing it with learners, I introduced buffering. The problem that we had in buffering was that learners needed to solve the problem of whether there was a hotel that would experience flooding and how they would use buffering.*" *(FGD)*
> **GT7**

The GT7 VRL observation extract below is consistent with the above extract. It also shows the following:

Teacher: *What is buffering?*

One learner: *To mark off an area around an object.*

Teacher: *OK, you mark off an area around an object. We have been able to define buffering now. Right?*

All learners: *Yes.*

Teacher: *All right. Write this statement, please. (writes on the chalkboard). You want to build a holiday resort but are concerned about flooding. Explain how buffering could assist you with a problem. I am giving you two minutes.*

All learners: *(discuss in groups)*

Teacher: *(Is moving around and assisting learners in groups).*

Teacher: *Anyone with an answer?*

One group member: Yes, *we can use sandbags to prevent…(inaudible)*

Teacher: *Yes. We can even use sandbags to demarcate or buffer that particular area.*

The extracts above by GT7 demonstrate that the co-researcher employed PBL to introduce buffering, where learners had to solve the problem of flooding that could have affected a hotel in a specific location and how buffering could be used to address the issue. Using PBL exposed learners to an opportunity to acquire buffering skills of geographic features in PBGIS. Yıldırım and Ünlü (2021) note that technology knowledge (TK) in TPACK suggests that geography teachers who can combine their technological skills with pedagogical and field knowledge are those who best meet today's educational needs. Hence, using PBL to teach PBGIS enabled learners to apply buffering skills in a way that aligned with their understanding of the concept, thereby avoiding flooding in the holiday resort they had to build in the scenario provided by the teacher. Manik (2022) points out that the mapwork section in geography encompasses geographical skills and techniques, where teachers need to prepare learners to acquire PBGIS skills in order to be part of a rapidly advancing, technology-driven world. Hence, the buffering activity the geography teacher gave learners might have made them more proficient in using buffering techniques effectively in other buffering activities, as they were equipped with the required skills through practice.

The VRL observation extract above, by GT7, shows that when using PBL to teach PBGIS, the co-researcher began by instructing learners to define the term 'buffering' before it was applied in a real-life experience to solve the problem. Beets and Le Grange (2008) and DBE (2012) reveal that the knowledge and understanding learning outcome (LO) is the second of three LOs for geography that have been identified based on the foundational competence for learners stipulated by the South African Qualifications Authority (SAQA). LO 2 stipulates that learners should demonstrate knowledge and understanding of geography concepts, processes, and spatial patterns. Therefore, the geography teachers began with the definition of buffering to ensure that learners understood and were clear about the concept before applying it to real-life experiences. For broader South African educational policy, this suggests a need to emphasise conceptual clarity, critical thinking, and local contextualisation within curricula, alongside professional support for teachers to implement these pedagogies effectively. Such policy shifts will be crucial in preparing learners for a digitally and geographically complex world.

The VRL observation extract above by GT7 also indicates that learners worked in groups to discuss the issue and were then able to find a solution, as one of the groups in their presentation proposed using sandbags to prevent the hotel area from experiencing flooding. Engaging learners in group discussions brings together learners from different backgrounds, skills, and views (Mzuza & van der Westhuizen, 2019; Santos & Castro, 2021). TPACK highlights that the skills learners need to be productive citizens of the 21st century include creativity and innovation, strong communication and collaboration skills, critical thinking and problem-solving, multiple literacies, and technology expertise (International Society for Technology in Education, 2007; Partnership for 21st Century Skills, 2011). Learners' diversity in group discussions led to more creative and innovative solutions to the problem, as group members contributed unique insights and approaches to the question posed by the teacher.

The findings show that the co-researcher adopted PBL to engage learners in using remote sensing to solve an environmental problem of their choice in their local communities. The reflection below by GT6 reveals the following:

> *"I think the method that dominated was problem-based learning. Learners were expected to identify the environmental problem in their local area and relate it to remote sensing as one of the GIS inputs. They were expected to examine how remote sensing can be used to address that environmental problem. So, they were given time as it was something they had to do in the classroom. They were given time to discuss and present." (FGD)* **GT6**

The GT6 VRL observation extract below aligns with the above extract. It also shows the following:

> ***Teacher:*** *We will be doing remote sensing. (writes on the chalkboard). As you know, even in grade 10, you learnt about remote sensing as one of the data inputs, which means we use remote sensing to get or access data. So, what we are going to do today is to organise yourselves into groups so that each group can come up with an environmental problem in the local area and tell us more about that problem. You will then tell us as a group how you could use remote sensing to deal with that particular environmental problem, as we know that GIS is used to solve problems.*
>
> ***All learners:*** *(learners discuss in groups)*
>
> ***Teacher:*** *(assisting learners while they are discussing).*
>
> ***Teacher:*** *Now, let us allow this group to present their answer. (Point a group in the front of the class)*
>
> ***One group member:*** *We identified that the problem we are facing in oShabeni is water scarcity. Firstly, I would like to discuss that water scarcity is the water shortage in an area. Remote sensing, which we are talking about, is about capturing data from a distance. Satellite images, which are examples of remote sensing, can be used to detect areas that are suffering from water shortage by identifying places that are dry or that have dry rivers. Therefore, this data can be collected and used to detect these areas and provide them with water resources. For example, water tanks can be sent regularly to provide people with water, or they can install water tanks to provide water. Thank you.*
>
> ***Teacher:*** *All right, since you do not have questions, it is fine. Now, the group has presented the problem and solutions well, but the group was not very clear about this remote sensing because the question is on remote sensing. So, the group should have focused more on using remote sensing and how it would help solve the problem. You have many stories about solving water scarcity, but you were unclear about how to use remote sensing to solve this problem. Let us give the second group a chance.*

The extracts above by GT6 indicate that the co-researcher adopted a PBL approach to instruct learners to work in groups and identify environmental problems in their local area. After that, learners had to use remote sensing to address environmental problems. Norton (2019) posits that group work creates a sense of shared responsibility in the knowledge-building process, and the more hands-on the activity is, the better the engagement of groups within the classroom. Working in groups to identify and solve a local area problem made learning more meaningful and applicable to learners' lives. It connected classroom knowledge to real-life problems they encountered in their communities. TK, under the TPACK conceptual framework, reveals that PBGIS knowledge in geography teaching should involve hands-on experience in real-life situations (Hill & Uribe-Florez, 2020). Hence, working on a local problem that directly impacts learners' surroundings makes them more engaged in learning when they see the practical implications of their efforts. Learners were required to connect their classroom knowledge of remote sensing to real-life problems they encountered in their communities.

The VRL observation extract above, as shown by GT6, indicates that one group identified water scarcity. The group defined the terms "water scarcity" and "remote sensing" and explained how they would address the problem of water scarcity in their local area using remote sensing. Like GT7, the extract above from GT6 once again highlights the importance of understanding the definitions of concepts before applying them to solve a problem. Naxweka and Wilmot (2019) explain pedagogical content knowledge (PCK) in mapwork and GIS as referring to a teacher's proficiency in presenting geographic concepts through various maps to promote learners' spatial thinking skills. Cronje (2020) warns that PBGIS key concepts and principles can be misconceived due to the lack of opportunities for gaining learner feedback, stemming from a large amount of one-way communication. Yıldırım and Ünlü (2021) state that geography teachers who can combine their technical skills with pedagogical and field knowledge are those who best meet today's educational needs. Engaging learners in discussions about water scarcity and remote sensing definitions enables them to access clear explanations of the concepts, eliminating ambiguity and promoting mutual understanding among learners before they engage in practical exercises using these concepts.

The findings also indicate that PBL was adopted to identify an ideal location for developing a cemetery using the Tlhabane Rustenburg topographic map. The comment and VRL observation below by GT10 indicate the following:

> "*The second one that I did was the problem-based method. I gave learners topographical maps of Tlhabane, Rustenburg. Learners were expected to identify a cemetery location from the maps. Therefore, we created a scenario in which the municipality wanted to develop a new cemetery. Now, they wanted the best location for the cemetery. Learners were expected to find the best location on the map.*" *(FGD)* **GT10**

The comment above aligns with the VRL observation extract below by showing how GT10 engaged learners to identify an ideal location for developing a cemetery through the PBL method. GT10 VRL observation extract indicates the following:

> ***Teacher:*** *OK, 3.2.2 Identify two data layers that can be used to identify the suitable cemetery site. Can we discuss in groups and come up with reasons?*
>
> ***All learners:*** *(discuss in groups).*
>
> ***Teacher:*** *(moves around and guides learners)*
>
> ***Teacher:*** *OK, I am giving you one minute to wrap up what you are doing, and then we discuss as a class so we can move on to the next slide. OK, are we done?*
>
> ***All learners:*** *Yes.*
>
> ***Teacher:*** *I will start with the first group and allow them to present the layers of information to us. One person from the group will explain and discuss the reasons. Please explain why they chose the layer when they wanted to develop a cemetery.*
>
> ***One group member:*** *(presents to the whole class). So, the question said we should identify the layers that can be used to identify a suitable site for developing a cemetery. So, as a group, we decided that because there is a layer of roads. Roads make it easy to access the cemetery. That is why the cemetery should be situated near roads. Then, if you look closely, you will see that there is availability of space, which means there is a land layer as there are no buildings or industries. So, there is land that can be used to give the cemetery more space for people to bury their loved ones.*
>
> ***Teacher:*** *OK, thank you—a round of applause.*
>
> ***All learners:*** *(Clap hands). T*
>
> ***Teacher:*** *There is a layer of roads, and the second layer is a layer of buildings. Aah. We said we must look for a vacant space. Ok.*

The extracts above by GT10 show that the co-researcher adopted PBL to present learners with a scenario in which they had to choose two data layers that could be used to identify a suitable cemetery site using the topographical maps of Tlhabane, Rustenburg. Ramsaroop (2018) notes that using PBL to teach PBGIS involves using maps for teaching and learning, where learners apply their mapwork, GIS, and problem-solving skills to real-life scenarios and demonstrate their understanding of the geographic concepts covered. The scenario the co-researcher presented required learners to understand data layering and the attributes of each data layer used to locate an ideal site for constructing the cemetery on the map. Santos & Castro (2021) note that content knowledge (CK) in TPACK indicates that teachers must be familiar with the content they will teach and understand how the nature of knowledge varies across different content areas. Being knowledgeable about the CK, the teacher, therefore, facilitated the group discussions to ensure learners moved in the right direction.

The excerpts above by GT10 also indicate that the co-researcher used PBL to allow learners to apply the data layering GIS concept to a real-life situation rather than merely theorising. Hlatywayo and Manik (2022) proposed that PBGIS topics should be taught in PBGIS laboratories, where learners are taught both theory and its practical application. They believe that this approach may improve PBGIS assessment performance in schools. Therefore, applying the theory might assist learners in better understanding and retaining knowledge of the data layering concept. Putri et al. (2021) note that incorporating TPACK into geography education can foster geographic thinking skills in learners, encompassing recall thinking, essential thinking, critical thinking, and creative thinking. The application of data layering might enhance problem-solving and critical-thinking skills as learners encounter real-life, authentic challenges and must find solutions.

6. Recommendations

Based on the findings of this study, it is recommended that curriculum developers, teacher training institutions, and education departments adopt PBL to enhance PBGIS teaching in a rural learning ecology where access to digital GIS tools is limited. Professional development programmes should be designed to equip teachers with the skills to implement PBL using PBGIS resources, such as printed maps, atlases, and layered spatial data. In addition, education policymakers should support the development and distribution of low-cost, high-quality PBGIS teaching materials that align with PBL methodologies. Teachers should also be encouraged to design real-world, context-specific problems that reflect local geographic issues, helping learners connect classroom content to their lived environments. By adopting PBL in teaching PBGIS, rural schools can foster critical thinking, spatial reasoning, and collaborative learning, even in the absence of technology. This approach not only enhances learner engagement but also promotes equity by ensuring that geographic education remains meaningful and effective across diverse learning ecologies. Geography teachers should also provide clear instructions, set clear and achievable objectives for the activity, and manage time.

7. Conclusion

This study explored how PBL can be adopted to enhance the teaching of PBGIS within a rural learning ecology. The findings demonstrate that while rural schools face significant challenges, such as limited access to digital GIS tools and constrained resources, teachers can still foster meaningful learning by using PBL strategies that promote critical thinking, collaboration, and real-world problem solving. By engaging with context-specific geographic issues through paper-based tools such as maps, atlases, and spatial data overlays, learners were able to develop key GIS concepts and spatial reasoning skills. The study also showed that PBL encouraged active learner participation and made geography more relevant and accessible, even in low-tech environments. Ultimately, adopting PBL in teaching PBGIS offers a practical, learner-centred solution for enhancing geography education in under-resourced settings. For this potential to be fully realised, continued support through teacher training, development of appropriate learning materials, and informed education policies is essential. This research contributes valuable insights into how innovative pedagogy can bridge technological gaps and support quality education in rural contexts.

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