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The Art of Documenting Scientific Knowledge: A Case Study of Two South African Grade 12 Science Teachers

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Abstract

The purpose of this article was to investigate and present effective strategies and innovative approaches that science teachers could employ to comprehensively and accurately document students' scientific knowledge. The study focused on addressing the challenges that arose during the documentation process and aimed to help teachers overcome these obstacles to ensure precise and thorough documentation of their students' scientific understanding. Two science teachers specializing in Physical Sciences and Life Sciences were interviewed through a phenomenological approach to gain insights into their perspectives and experiences. The findings demonstrated that incorporating multiple tasks, such as practical investigations, concept maps, mind maps, research projects, and group discussions, enhanced students' comprehension, and engagement with scientific concepts. These strategies accommodated diverse learning styles and abilities, fostering inclusivity, and facilitating a comprehensive learning experience. The study also highlighted the challenges posed by limited resources and restricted access to laboratory equipment, proposing the adoption of innovative assessment methods, including virtual simulations, to overcome these limitations. The implications of the study underscored the importance of comprehensive teacher training, resource allocation, collaborative approaches, integration of technology, and curriculum design aligned with the documentation of scientific knowledge. The ultimate objective of this article was to contribute to the enhancement of science education and promote scientific literacy by offering practical insights for science teachers in effectively documenting students' scientific knowledge.

Keywords: Documenting Scientific Knowledge, Physical Sciences, Life Sciences

INTRODUCTION

The study sought to identify the barriers faced by South African science teachers during the documentation of their students' scientific knowledge while also showcasing the innovative methods and strategies they employ. The objective was to provide scientifically validated strategies and best practices for science teachers to accurately document students' scientific knowledge (Du & Liu, 2021). The study systematically addressed the inherent challenges associated with the documentation process and strongly advocated for active student involvement, utilization of innovative methods, and integration of suitable tools. These measures underlined the paramount importance of precision, accessibility, and reproducibility in recording scientific knowledge for science teachers.

The process of documenting students' scientific knowledge, as meticulously defined by Kim and Kwon (2020), entails a comprehensive collection and meticulous organization of data on students' comprehension of scientific concepts, skills, and practices. Lorenzo et al. (2021) assert that effective documentation of students' scientific knowledge necessitates the creation of ample opportunities for collaboration, reflection, and peer discussion during experimental exercises. Through diligently implementing these practices, Lorenzo et al. (2021) proposed a

significant enhancement of students' science communication skills and overall understanding, concurrently affording them valuable feedback on their ideas.

Drawing parallels with the seminal works of Kim and Kwon (2020) and Lorenzo et al. (2021), Hand et al. (2019) also accentuated the profound significance of capturing students' scientific knowledge as a pivotal approach to effectively assess their learning progress. Consequently, these esteemed scholars mutually concur that those assessments impeccably capturing students' scientific knowledge bear great importance. Such assessments not only serve as a robust metric to measure learning outcomes but also act as catalysts in cultivating a profound grasp of scientific principles and skills among students. Moreover, they assume an indispensable role in apprising science teachers of their students' level of comprehension, thus effectively guiding instructional methodologies and shaping science education practices to foster optimal learning outcomes. a crucial role in preparing students to meet the demands and challenges of STEM fields in society.

The above perspective is supported by the South African Curriculum and Assessment Policy Statement (CAPS), which places emphasis on practical scientific inquiry, the development of problem-solving skills, and the interconnectedness of science, technology, society, and the environment (Department of Basic Education, 2019). Consequently, it is crucial for teachers to employ diverse strategies and assessment tools to accurately capture and evaluate students' scientific knowledge. Effective strategies and assessment tools that can be utilized include performance-based assessments (Hammerness & Klette, 2020), concept maps (Brinks Lockwood & Oliveira, 2019), written assessments (Graesser et al., 2019; Pedrosa-de-Jesus & Moreira, 2020), multiple-choice questions (Caviglia et al., 2019), observations, and interviews (Menon & Johnson, 2020; Palmquist & Crowley, 2019), and rubrics (Gaudino & Fariña-López, 2019). Employing these tools and approaches allows for a comprehensive and accurate assessment of students' scientific knowledge.

In our rapidly evolving world, scientific knowledge holds increasing importance in shaping our lives and society. Hence, it is crucial to provide students with a strong foundation in science education that nurtures their fundamental scientific knowledge and equips them with the essential skills to navigate and contribute to the scientific domain. Researchers have consistently highlighted the significance of documenting students' scientific knowledge for the improvement of science education on a global scale. Lee and Linn (2019) affirmed that documenting students' scientific knowledge is vital for informing teaching practices, curriculum design, and educational policies. This practice enables teachers to analyze students' knowledge, adapt their teaching approaches, and develop curricula that align more effectively with students' learning needs, thereby promoting scientific literacy.

Moreover, Cheng and Chiu (2020) emphasized the importance of documenting students' scientific knowledge in enhancing learning, identifying misunderstandings, and fostering lifelong learning. Through monitoring students' progress over time, teachers can design targeted interventions to address areas where students face challenges, correct misconceptions, and encourage lifelong learning beyond formal education (Hattie & Timperley, 2007).

Problem statement

In the African context, researchers have underscored the significance of documenting students' scientific knowledge as a way to foster equal opportunity and access to science education by identifying and addressing inequalities (Sayed & Jita, 2020). Moreover, documenting scientific knowledge contributes to the promotion of inclusive education for marginalized students, thereby supporting the achievement of Sustainable Development Goals (Pandian & Naidoo, 2021). Additionally, this practice addresses the challenges faced by the continent by developing context-specific science education that informs curricula (Adeyemo & Akinsola, 2016).

Nonetheless, the accurate documentation of students' knowledge within the South African educational system is hindered by various challenges, such as limited resources, inadequate teacher training, and socioeconomic inequalities (Van Wyk & Lemmer, 2019). Insufficient laboratory equipment, outdated teaching materials, and a lack of technological infrastructure further impede the collection of data (Kamba et al., 2019). In addition, the lack of proper teacher training poses significant obstacles to capturing and interpreting students' scientific knowledge effectively (Holmqvist, 2019). Therefore, these challenges collectively underscore the urgent need for comprehensive support and targeted interventions to address the limitations associated with accurately documenting students' scientific knowledge within the South African educational system.

Significance of the Study

The significance of this study is rooted in the pressing need to enhance science education in the African context, with a specific focus on South Africa. Through emphasizing the importance of documenting students' scientific knowledge, the study aimed to identify the obstacles faced by South African teachers during the documentation process. Furthermore, by showcasing innovative methods and strategies employed by South African teachers, the study sought to provide practical insights into accurately capturing students' comprehension of scientific concepts and skills within the science classroom, despite the prevailing challenges. Ultimately, the study aspired to contribute to the broader objectives of improving science education and promoting scientific literacy in South Africa. The central research question

guiding this study was: *"What are the experiences, perspectives, and practices of science teachers regarding the documentation of students' scientific knowledge?"*

Theoretical framework

The study is grounded in a multi-theoretical framework that combines the social-constructivist theory of learning and Assessment for Learning principles. The social-constructivist theory, as established by Vygotsky (1978) and supported by Wertsch (1985), emphasizes the social and active nature of learning, highlighting that students construct knowledge through interactions with others and their environment. Within this framework, teachers have a crucial role as facilitators, while students actively participate in collaborative knowledge generation. Bandura (1986) and Salomon & Perkins (1998) further emphasize the significance of teachers being aware of students' prior knowledge and experiences to create learning opportunities that build upon their existing understanding. As a result, students are encouraged to engage in joint discussions, activities, and effectively document their scientific understanding, as highlighted by Resnick (1991).

The assessment for learning approach, developed by Black and Wiliam (1998), is designed to enhance learning outcomes by employing formative assessment techniques. The assessment for learning approach aligns with the social-constructivist theory by focusing on formative assessment techniques that support ongoing learning and improvement of students' scientific knowledge (Sadler, 1989). The assessment for learning approach places a strong emphasis on providing timely feedback, which is essential for learners to reflect on their understanding, identify areas for improvement, and adjust their learning strategies. Therefore, by actively engaging students in the assessment process, this approach encourages them to take ownership of their learning and set goals for further development (Hattie and Timperley, 2007). Consequently, integrating the assessment for learning approach within the social-constructivist framework provides an effective means to document students' scientific knowledge. It allows teachers to collect valuable data through formative assessment activities that capture students' understanding, progress, and areas for improvement. This approach empowers students to be actively involved in their assessment, promoting self-reflection and metacognitive skills. Therefore, by employing both the social-constructivist theory and the Assessment for Learning approach, teachers can foster a supportive and engaging learning environment that nurtures students' scientific understanding and skills. This integration of theoretical perspectives enhances the process of documenting students' scientific knowledge and contributes to the overall improvement of science education outcomes.

METHOD

Research Design

The study followed an interpretivist paradigm and utilized a phenomenological research design to explore the perspectives and experiences of science teachers regarding the documentation of students' scientific knowledge. Employing a qualitative research approach, the study utilized a case study design to conduct a comparative analysis of two Grade 11 science teachers specializing in Physical Sciences and Life Sciences. This design allowed for a thorough investigation of the teachers' perspectives and practices related to the documentation of students' scientific knowledge, resulting in comprehensive and nuanced insights (Merriam, 2009).

Sampling

Two Grade 11 science teachers, one specializing in Physical Sciences and the other in Life Sciences, were purposefully selected from a public school in the Diepkloop district of Soweto, South Africa. In the South African context, Physical Sciences and Life Sciences are distinct subjects. Physical Sciences focus on the study of non-living matter and energy, whereas Life Sciences center on living organisms and their processes. Both subjects are integral in providing students with valuable insights into the natural world and nurturing scientific literacy.

The selection criteria were based on the two science teachers' expertise and knowledge in documenting students' scientific knowledge. Despite challenges posed by limited teaching and learning resources in public schools (Naidoo, 2016), the selection of these teachers allows for a comparative analysis of their documentation practices. Through comparing their approaches, a deeper understanding of documentation within the school context can be gained, leading to valuable recommendations for improving scientific knowledge documentation in both disciplines.

Data Collection

The study employed semi-structured interviews as the primary data collection method to gain in-depth insights into the perspectives and challenges of science teachers when documenting students' scientific knowledge. Face-to-face interviews were conducted during the teachers' lunch breaks, and audio recordings were used to ensure the accuracy and reliability of participant responses. Semi-structured interviews were chosen for their flexibility in questioning and comprehensive exploration, aligning with the study’s objectives and the goal of obtaining rich and contextually embedded data. To ensure the validity of the instrument, a pilot group was involved in refining the interview schedule, improving its effectiveness in capturing relevant data.

Data Analysis

The collected data underwent a descriptive analysis approach, involving the transcription, organization, and analysis of data to identify common themes and unique aspects related to the teachers' adoption of blended practices. The close-reading approach was employed, with transcripts and audio recordings being carefully examined multiple times to gain a deep understanding of the data and uncover themes and nuances in participants' language, perspectives, and experiences. To ensure the accuracy and reliability of the data, member checking was conducted, allowing participants to review the audio recordings and provide feedback or clarification, thereby ensuring the validity of the collected information. Ethical considerations were thoroughly addressed by obtaining ethical clearance from the University of South Africa's College of Education and adhering to the necessary ethical guidelines and protocols.

RESULTS AND DISCUSSION

The study was conducted in a public school in the Diepkloop district of Soweto, South Africa. This setting accurately represents the real-world challenges faced by science teachers in terms of limited resources and restricted access to laboratory equipment, common issues in public schools, which can impact the quality of science education. The study employed a phenomenological design to explore science teachers' perspectives and experiences in documenting their students' scientific knowledge, providing in-depth insights into teachers' practices and innovative strategies to overcome challenges. Despite encountering difficulties, the teachers exhibited resilience and resourcefulness, implementing innovative methods to effectively document scientific knowledge. The results identified four key themes that emphasized the teachers' dedication to comprehensively assess students' academic understanding in an engaging manner.

Theme 1: Use of multiple tasks

The theme of utilizing a variety of projects to document students' scientific knowledge emerged from the responses of both the Physics Teacher and the Life Sciences Teacher. When asked about their strategies, both teachers mentioned employing different types of projects to cater to diverse learning styles and abilities among their students. The emergence of this theme highlights the teachers' recognition of the importance of adopting multiple assessment methods to document students' scientific knowledge effectively. Both teachers demonstrate a student-centered approach by tailoring their assessment strategies to accommodate different learning styles and abilities. The theme also aligns with the study's aim to explore innovative methods for documenting scientific knowledge, contributing to a comprehensive and engaging learning environment.

The Physics Teacher emphasized the use of experiments and laboratory reports as primary tools to document students' scientific knowledge. The teacher mentioned that by incorporating practical investigations, they are able to *"Facilitate the development of a deeper understanding of scientific concepts, enhance practical skills, and equip students for future careers in the field of science."* This approach aligns with the Assessment for Learning principles, as it provides students with opportunities for hands-on learning and active engagement in the scientific process. Additionally, the mention of equipping students for future careers in the field of science suggests that the teacher aims to foster practical skills that are valuable in scientific professions.

On the other hand, the Life Sciences Teacher went beyond traditional practical and written assessments to employ additional approaches, indicating that: *"I provide my students with research projects centered around specific Life Sciences themes. They are required to complete and report on these projects through a combination of research, group discussions, and quizzes. This approach ultimately leads to a more comprehensive understanding of their scientific knowledge."* This multifaceted approach required students to complete and report on these projects through a combination of research, group discussions, and quizzes. Therefore, by using these diverse methods, the Life Sciences Teacher seeks to ensure a more comprehensive understanding of students' scientific knowledge. This approach allows students to explore various aspects of the subject matter, collaborate with peers during group discussions, and apply critical thinking skills in the research process. The inclusion of quizzes may serve as a formative assessment tool to gauge students' understanding throughout the project.

The results suggest that both the Physics Teacher and the Life Sciences Teacher employ innovative and multifaceted approaches to effectively document students' scientific knowledge. This is evident as both teachers' approaches surpass traditional practical and written assessments, highlighting the significance of diverse assessment methods to comprehensively capture students' scientific knowledge. Through incorporating engaging and interactive activities, both teachers demonstrate their dedication to creating a supportive and inclusive learning environment that caters to diverse learning styles and abilities. The results also indicate that both teachers' strategies align with the broader objective of promoting scientific literacy and fostering a deeper understanding of scientific concepts among students. Therefore, by providing opportunities for students to actively engage with scientific principles and apply critical thinking skills, the teachers are likely to enhance students' overall comprehension of the subject matter. These results underscore the importance of innovative assessment techniques to enhance science education outcomes and cultivate students' scientific understanding.

The findings of this study demonstrate that both the Physical Sciences and Life Sciences teachers employ diverse strategies to effectively document students' scientific knowledge.

These results are consistent with previous studies emphasizing the significance of incorporating a wide range of activities for documenting scientific knowledge. Aji and Khan (2019) have highlighted the advantages of including varied tasks that cater to different learning styles and skills, leading to increased engagement, motivation, retention, and heightened awareness of the relevance of science in daily life. Similarly, Lopez (2008) suggests that adopting a multimodal approach to documenting scientific knowledge enables teachers to better address the diverse learning styles and abilities of their students.

The utilization of multiple tasks for documenting students' scientific knowledge is crucial in science education, as underscored by Osborne et al. (2003). Effective assessment of students' understanding and knowledge in science education requires careful consideration of different assessment methods and tasks to gather comprehensive and reliable information. Studies consistently demonstrate that incorporating a range of activities accommodates diverse learning styles and abilities, promotes higher engagement and motivation, and facilitates greater retention and appreciation of the significance of science in daily life (Aji & Khan, 2019). Much like Gholam (2019), incorporating various tasks such as practical investigations, laboratory reports, research projects, group discussions, and quizzes, both teachers in this study exhibited a commitment to providing a comprehensive and engaging learning experience for their students, reflecting a more student-centered approach. This comprehensive approach allows students to actively engage with scientific concepts, apply critical thinking skills, collaborate with their peers, and explore different aspects of the subject matter (Garrett, 2008). The findings reinforce the notion that diverse assessment methods play a pivotal role in capturing students' scientific knowledge accurately and holistically.

Furthermore, the results align with the study conducted by Vieira and Tenreiro-Vieira (2016) in promoting scientific literacy and fostering a deeper understanding of scientific concepts among students. Hsbollah and Hassan (2022) argue that by providing opportunities for students to actively participate in the scientific process and interact with scientific principles in real-life contexts, teachers facilitate a deeper and more meaningful learning experience. This approach not only enhances students' comprehension of scientific concepts but also fosters an appreciation for the relevance and significance of science in their lives.

Therefore, the findings underscore the significance of employing diverse assessment strategies to effectively document students' scientific knowledge. Both the Physics Teacher and the Life Sciences Teacher demonstrated the value of incorporating various tasks to accommodate diverse learning styles and abilities, resulting in heightened engagement, motivation, and retention of scientific knowledge. Thus, by offering students opportunities for active engagement with scientific concepts and the application of critical thinking skills,

teachers can foster a deeper understanding of science and promote scientific literacy among their students. These results carry implications for science education, emphasizing the importance of embracing a comprehensive and multifaceted approach to assess students' scientific understanding accurately and holistically.

Theme 2: Science practical investigations

The results obtained from the responses of both the Physical Sciences and Life Sciences teachers emphasize the significance of practical investigations in science education. The emergence of the theme of science practical investigations from the responses of both Physical Sciences and Life Sciences teachers highlights their acknowledgment of the valuable contribution of practical investigations to students' understanding and engagement with scientific concepts. This theme underscores the importance of integrating hands-on learning experiences and real-world applications of scientific principles to enhance students' comprehension and interest in science education.

The Physical Sciences teacher emphasized that *"I use practical investigation because it allows my students to engage in hands-on learning experiences that can help them better understand complex scientific ideas. Additionally, practical investigation facilitates the concrete documentation of students' observations, hypotheses, and conclusions, leading to a more comprehensive understanding of scientific concepts."* Through active participation in experiments and investigations, students are more likely to grasp scientific concepts and principles at a deeper level. Moreover, practical investigation provides an opportunity for students to concretely document their observations, hypotheses, and conclusions, which contributes to a more comprehensive understanding of scientific concepts. This aligns with the research objective of exploring how teachers document students' scientific knowledge, as practical investigations offer a tangible and experiential approach to this process.

Similarly, the Life Sciences teacher highlighted that *"Through emphasizing the real-world application of scientific concepts and principles, these practical investigations can help my students see the relevance of what they are learning to their daily lives, making the subject matter more engaging and meaningful to them."* Therefore, by showcasing the relevance of what students are learning to their daily lives, practical investigations make the subject matter more engaging and meaningful to them. When students can connect scientific concepts to real-life situations, they are more likely to be motivated and interested in the learning process. This aspect relates to the research objective of exploring teachers' perspectives and experiences in documenting students' scientific knowledge. Practical investigations allow teachers to contextualize scientific concepts and demonstrate their significance in the real world, fostering a deeper understanding and appreciation of science among students.

The results highlight the significant impact of practical investigations in science education, fostering students' understanding, engagement, and application of scientific knowledge. Hands-on learning experiences deepen comprehension of complex scientific ideas and make the learning process more engaging and meaningful. Practical investigations also serve as a valuable tool for documenting students' scientific knowledge, allowing teachers to assess comprehension and provide prompt feedback. Moreover, integrating practical investigations promotes critical thinking and analytical skills, nurturing students' problem-solving abilities.

Beyond academic benefits, practical investigations foster student motivation and interest in science education. The real-world application of scientific concepts makes the subject matter more relatable and meaningful to students. When students can connect scientific concepts to real-life situations, they develop a genuine interest in the subject, leading to increased motivation to learn and explore further. These results underscore the importance of incorporating practical investigations in science education, as they enrich the learning experiences of students and inspire a lifelong curiosity for scientific exploration. Integrating practical investigations into science curricula significantly enhances students' overall learning outcomes.

The findings of this study are consistent with prior research conducted by Miller and Abrahams (2010), underscoring the critical role of practical investigation in enriching students' understanding of scientific concepts. Practical investigation enables students to actively participate in experiments and laboratory work, providing valuable hands-on learning experiences (Shana & Abulibdeh, 2020). This active engagement, coupled with the encouragement of research and questioning, contributes to a deeper comprehension of scientific topics. The perspectives of both Physical Sciences and Life Sciences teachers in this study further corroborate these findings, emphasizing the importance of practical investigation in science education. The integration of practical investigation in science classes is essential, as it offers students tangible experiences that foster a deeper grasp of complex scientific ideas (Hofstein & Lunetta, 2004). Through practical investigation, students have the opportunity to document their observations, formulate hypotheses, and analyze their findings, resulting in a more comprehensive understanding of scientific principles (Abrahams & Millar, 2008). These benefits align with the outcomes of Sani's (2014) study, reinforcing the viewpoints expressed by the Physical Sciences and Life Sciences teachers in this research. The efficacy of practical investigations has been demonstrated by Constantinou and Fotou (2020), highlighting them as a "Must-Have Practical Work in Tertiary Life Science Education." Thus, the findings of this

study, along with previous research, collectively emphasize the significance of practical investigation in enhancing students' understanding of scientific concepts.

Similar to Harde et al. (2010), the integration of practical investigations into science education enables teachers to create dynamic and engaging learning environments that foster active participation and critical thinking among students. As mentioned by Shana and Abulibdeh (2020), the tangible nature of practical investigations allows students to connect theoretical knowledge with real-world applications, deepening their appreciation for the relevance of science in their lives. Moreover, the hands-on experiences provided by practical investigations contribute to increased student motivation and interest in the subject, ultimately fostering a lifelong curiosity and passion for scientific exploration.

Consequently, as science education continues to evolve, the significance of practical investigation remains vital in preparing students for future challenges in scientific fields. These findings, in conjunction with previous research, underscore the ongoing importance of incorporating practical investigations into science curricula to enhance students' understanding and appreciation of scientific concepts. Therefore, by leveraging the power of hands-on learning experiences and encouraging student inquiry, educators can empower the next generation of scientists and critical thinkers, paving the way for advancements and discoveries in the world of science.

Theme 3: Strategies for formative assessment

The theme of employing a variety of strategies for formative assessment to assess and enhance students' understanding of scientific concepts emerged from the responses provided by both the Physical Sciences and Life Sciences teachers. Both teachers emphasized the significance of utilizing diverse tools and methods to effectively gauge students' comprehension of scientific concepts. The emergence of this theme highlights the importance of incorporating various formative assessment techniques in science education to bolster students' learning and comprehension of scientific concepts. Consequently, by providing multiple opportunities for students to demonstrate their understanding through different tasks and activities, teachers can more effectively identify areas where students may require additional support or clarification.

The Physical Sciences teacher indicated that they use concept maps and mind maps as formative assessment tools *"To help students consolidate their knowledge and identify any gaps in their understanding, which I consider as a form of formative assessment."* This indicates a student-centered approach to learning. These visual representations allow students to organize their knowledge and identify connections between different scientific concepts. Therefore, by utilizing concept maps and mind maps, the teacher can gain insights into students' thought processes and identify any misconceptions or gaps in their understanding. This approach aligns

with the research question regarding the strategies employed by teachers to assess and enhance students' understanding of scientific concepts.

Similarly, the Life Science teacher stated, *"For some of the formative assessments, I use research projects and group discussions, such as debates and discussions, to assess my students' comprehension of scientific concepts."* These formative assessments reflect an emphasis on active learning and collaborative engagement. Therefore, by engaging students in research projects, the teacher encourages them to explore scientific concepts in depth, apply critical thinking skills, and communicate their results effectively. The use of group discussions, debates, and discussions promotes peer interaction and the exchange of ideas, fostering a deeper understanding of scientific concepts. This approach also aligns with the research question concerning the methods employed by teachers to assess and enhance students' comprehension of scientific concepts.

The results demonstrate that both Physical Sciences and Life Sciences teachers recognize the significance of formative assessment in evaluating and enhancing students' comprehension of scientific concepts. They implement diverse formative assessment strategies customized to their respective subjects and teaching methodologies, underscoring a learner-centric approach to education. The Physical Sciences teacher employs concept maps and mind maps as tools to aid students in consolidating their knowledge and identifying any gaps in their understanding. These visual aids empower students to structure information and establish correlations among scientific concepts, yielding valuable insights into their cognitive processes and areas requiring further assistance. In contrast, the Life Science teacher utilizes research projects and group discussions, including debates, to emphasize active learning and collaboration. Research projects encourage in-depth exploration of scientific concepts, fostering critical thinking skills and effective communication. Group discussions facilitate peer interaction and the exchange of ideas, nurturing a deeper comprehension of scientific principles.

The integration of concept maps and mind maps as formative assessment tools in science education is well-supported by existing research, which highlights the effectiveness of visual aids in enhancing students' comprehension of complex scientific topics (Beaudry & Wilson, 2009). Concept maps, as emphasized by Novak & Caas (2006), provide valuable means for students to organize and establish connections between different pieces of information in a meaningful way. By visually representing the relationships between various scientific concepts, concept maps facilitate a deeper understanding of the subject matter. Similarly, mind maps have been shown to stimulate idea generation and the integration of diverse information, leading to improved knowledge construction and better recall of scientific concepts (Arulselvi, 2014). When utilized in formative assessments, these visual tools become powerful resources for

science teachers to help students consolidate their knowledge and identify gaps in their understanding (Fisher and Frey, 2014). Davies (2011) suggests that as students engage in creating concept maps or mind maps to depict their grasp of scientific concepts, they are encouraged to think critically about the interrelationships between different ideas and concepts. Moreover, as emphasized by Shabiralyani et al. (2015), the process of constructing these visual representations aids in reinforcing the information in their minds, facilitating easier recall and application of knowledge in various contexts.

Furthermore, the inclusion of research projects and group discussions as formative assessment methods aligns with the guidelines outlined in the CAPS document, which underscores the significance of formative assessment in documenting students' learning progress. Research projects, as emphasized by Nold (2010), offer students a valuable opportunity to develop essential research skills and cultivate critical thinking abilities while actively engaging with scientific concepts. Through immersing themselves in research, students not only gain a deeper understanding of the subject matter but also learn how to analyze and interpret scientific data, draw evidence-based conclusions, and hone their analytical and problem-solving capabilities. Additionally, as seen in Zambrano et al.'s (2019) study, the collaborative nature of group discussions enhances students' learning experience by fostering an environment where they can exchange ideas, question one another's viewpoints, and develop a deeper appreciation for various perspectives on scientific topics.

In conclusion, the integration of concept maps, mind maps, research projects, and group discussions as formative assessment tools in science education can significantly enhance students' understanding of complex scientific concepts. These visual and interactive methods not only promote critical thinking and knowledge retention but also cultivate essential research and collaborative skills, aligning with the goals of comprehensive science education. As educators continue to explore and implement effective formative assessment strategies, these approaches hold great promise in fostering a deeper and more meaningful learning experience for students in science classrooms.

Theme 4. Challenges in documenting students' scientific knowledge

The theme of challenges in documenting students' scientific knowledge emerged from both teachers' responses when questioned about difficulties they encountered and their approaches to overcoming them. They expressed concerns about the insufficient availability of apparatus or laboratory equipment in their school, which hindered their ability to conduct prescribed investigations or experiments, especially during summative assessments. This theme highlights the significant impact of limited resources and restricted access to laboratory equipment on the documentation process, affecting the effective capture of students' scientific

knowledge, particularly in practical assessments. Addressing resource limitations in science education is crucial to ensure a more comprehensive and accurate assessment of students' scientific understanding. The teachers' experiences with these challenges underscore the need for innovative strategies and adaptations to overcome constraints imposed by inadequate resources in effectively documenting students' scientific knowledge.

The results of this study shed light on the challenges faced by both the Life Sciences and Physical Sciences teachers in documenting students' scientific knowledge, particularly in the context of limited resources and access to laboratory equipment. Both teachers emphasized the significance of practical investigations and experiments as part of the curriculum and summative assessment. However, the lack of necessary apparatus and laboratory equipment posed obstacles to effectively implementing these assessments. In response to these challenges, both teachers demonstrated resilience and innovation by adopting alternative assessment methods to capture students' scientific understanding.

The Life Sciences teacher embraced project-based assessments, group discussions, and practical demonstrations as effective alternatives. They stated, *"As a Life Science teacher, I face challenges in documenting my students' scientific knowledge due to limited access to laboratory equipment and resources. To address these challenges, I advocate for innovative and engaging assessment methods. Project-based assessments, group discussions, and practical demonstrations are effective alternatives that capture students' understanding and promote active learning. Therefore, by integrating these strategies, I can overcome limitations and provide comprehensive documentation of students' scientific knowledge."* These approaches promote active learning and allow students to engage with scientific concepts in meaningful ways, enabling the teacher to overcome limitations and provide comprehensive documentation of students' scientific knowledge.

Similarly, the Physical Sciences teacher recognized the importance of practical experiences but faced resource constraints. However, they emphasized the use of alternative methods such as student presentations, virtual simulations, and online experiments to address these challenges. The teacher stated, *"The limited availability of resources in this school presents challenges when documenting students' scientific knowledge through practical investigations. To overcome these obstacles, I adopt alternative assessment methods that promote student engagement and practical learning experiences. One such strategy is encouraging students to create presentations, which allows them to demonstrate their understanding of scientific concepts as a form of formative assessment. Additionally, I incorporate virtual simulations and online experiments to provide practical experiences in a digital format for summative assessments. Therefore, by implementing these alternative*

methods, I am able to assess students' comprehension while offering interactive learning opportunities. Despite the constraints imposed by limited resources, I remain dedicated to creating an engaging learning environment that fosters the application of scientific knowledge." These innovative approaches enabled students to apply their scientific knowledge in a more interactive manner, despite the lack of physical laboratory equipment, ensuring that students could actively engage with scientific concepts and receive a meaningful assessment of their understanding.

The results suggest that both Life Sciences and Physical Sciences teachers face challenges in documenting students' scientific knowledge due to limited access to laboratory equipment and resources, which are essential components of scientific assessment in both subjects. However, the teachers have taken a proactive approach to address these challenges by adopting innovative and alternative assessment methods. The Life Sciences teacher advocates for project-based assessments, group discussions, and practical demonstrations to engage students in hands-on activities that simulate practical experiences. Similarly, the Physical Sciences teacher encourages students to create presentations, uses virtual simulations, and conducts online experiments to assess their comprehension effectively. Despite the constraints posed by limited resources, both teachers remain dedicated to creating an engaging learning environment that fosters the application of scientific knowledge. They are resourceful and adaptable, using innovative approaches to overcome challenges related to limited laboratory equipment and resources.

The study provided emphasizes the significant challenges encountered by Life Sciences and Physical Sciences teachers in public schools due to the absence of functional laboratories (Barrett et al., 2019). This limitation can hinder the traditional methods of documenting students' scientific knowledge. However, it is crucial to avoid allowing these challenges to obstruct the assessment of students' comprehension of scientific concepts. Instead, educators should prioritize embracing innovative and alternative assessment methods, as recommended by Stears and Gopal (2010). One effective approach to evaluate students' knowledge is through project-based assessments, advocated by Krajcik and Shin (2014). By encouraging students to apply their knowledge and skills to real-world scenarios, this method not only enhances their understanding of scientific concepts but also fosters the development of practical skills beyond theoretical comprehension.

In addition to project-based assessments, group discussions play a significant role in promoting collaboration, idea exchange, and critical thinking among students (Alsaleh, 2020). These interactive discussions can substantially contribute to enhancing students' understanding and overall learning experience in science. Furthermore, despite the limited availability of

conventional laboratory resources, technological advancements have introduced virtual simulations, such as virtual laboratories, as powerful tools to provide practical learning experiences in a digital format. According to Jara et al. (2011), these virtual experiences enable students to explore and manipulate scientific phenomena, effectively bridging the gap left by the absence of physical laboratories. Consequently, students can develop a robust understanding of scientific concepts and acquire valuable scientific skills through these virtual experiences.

Therefore, by embracing these innovative assessment methods, teachers can surmount the challenges posed by the limited availability of laboratory resources in public schools. These methods offer valuable alternatives to ensure students receive a comprehensive education in science, enabling them to excel in their scientific pursuits and contribute effectively to the ever-evolving world of science. As educational institutions continue to adapt and evolve, the integration of technology and innovative assessment approaches can lead to enhanced learning outcomes for students in science education.

CONCLUSION

The study, conducted in a real-world public-school setting in South Africa, revealed the challenges faced by science teachers due to limited resources and restricted access to laboratory facilities. However, despite these hurdles, the teachers demonstrated resilience and adaptability by utilizing innovative assessment methods. The study identified four key themes: the use of multiple tasks to accommodate diverse learning styles, the significance of practical investigations, strategies for formative assessment, and the difficulties in documenting students' scientific knowledge. The study recommends embracing innovative assessment techniques, leveraging practical investigations, and addressing resource constraints in science education. Therefore, by adopting these measures, educators can foster a deeper comprehension of scientific concepts among students and prepare them to tackle future challenges in scientific fields.

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