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ORIGINAL ARTICLE

An Assessment of Teacher Professional Development Interventions for the Integration of Indigenous Knowledge in Science

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ABSTRACT

A professional development intervention (PDI) was developed for science teachers, focusing on pedagogies to integrate indigenous knowledge (IK) into school curriculum topics. The study aimed to determine which characteristics of science PDIs were imperative to support teacher learning and influence teacher practice for IK integration in science curriculum themes. The conceptual framework encompassed pedagogical content knowledge (PCK), teacher views on the nature of indigenous knowledge (VNOIK), and Guskey's evaluation framework. The interviews with 62 teachers and the analysis of teacher portfolios, RTOP, and VNOIK revealed that a practical approach to integrating IK into the science curriculum involves providing PD opportunities. These PD opportunities enable teachers to enhance their teaching practices, fostering reflection and the practical application of acquired knowledge within their professional contexts. The study's uniqueness lies in how the PDI was conceptualized and implemented to support professional learning aimed at IK integration in science teaching.

KEY WORDS: Guskey's evaluation framework; indigenous knowledge; pedagogical content knowledge; reformed teaching practices; views on the nature of indigenous knowledge

INTRODUCTION

Education's evolution to meet 21st-century demands underscores the necessity of aligning teacher professional development interventions (PDIs) with students' evolving needs. This study delves into the interplay between effective teacher PDIs, pedagogical practices, and systemic pressures that influence reformed teaching practices, resource availability, critical teacher reflection, and integrating indigenous knowledge (IK) into science education. Teacher professional development (PD) has adapted significantly to the contemporary educational landscape, characterized by dynamic demands (Sancar et al., 2021). Darling-Hammond et al. (2017) identified seven essential characteristics of effective PDIs: Content focus, active learning, collaboration, modeling, coaching, feedback, and sustained duration. This study explicitly examines the content aspect of PDIs, with a particular focus on integrating IK into science teaching.

Teacher PD is inherently complex, evolving throughout a teacher's professional journey, guided by a framework proposed by Sancar et al. (2021). This framework underscores the significance of context-oriented support, a theme that aligns with the present study's exploration of teacher PD effectiveness through teachers' perspectives on IK integration in science education. Collaboration among educators and their active engagement in discussions about teaching strategies and resources have been associated with positive student outcomes (Frumin et al., 2018). In addition, integrating teacher PD with curriculum planning has shown promise in localized interventions (Kelly et al., 2019). However, the growing demand for effective teacher PDIs necessitates facilitating large-scale initiatives to meet evolving educational needs.

Global research suggests that teacher PDIs can be equally effective in scaled programs, which provided that they embody key characteristics proposed by Sancar et al. (2021). Guskey (2002) emphasized PD evaluation levels, focusing on teacher learning, organizational support, skills application, and student impact, all of which are critical for successful IK integration in science curriculum themes. The transformative potential of teacher PDIs equips educators with the pedagogical strategies and pedagogical content knowledge (PCK) necessary for successfully incorporating complex topics such as IK into science teaching. PCK, defined by Shulman (1986), fuses pedagogical and content knowledge and plays a pivotal role in influencing student outcomes and benefiting students (Pitjeng-Mosabala and Rollnick, 2018). The present study employs the Reformed Teaching Observation Protocol (RTOP; Piburn and Sawada, 2000) to assess PCK, providing valuable insights into the extent to which IK is effectively incorporated into the science classroom.

The present study aims to examine the effectiveness of PDIs in equipping science teachers with the necessary pedagogical strategies to integrate IK into science education. Specifically, it seeks to identify the critical characteristics of effective PDIs that facilitate teacher learning, instructional transformation, and sustainable IK integration. By addressing this objective, the study builds on existing research by bridging the gap between theoretical discussions on IK integration and practical, evidence-based strategies for implementation in science classrooms. Unlike previous studies focusing predominantly on theoretical justifications for IK inclusion, the present research presents an empirical evaluation of a structured PDI designed to enhance teachers' PCK and reflective practices. Furthermore, it contributes to the broader discourse by aligning PDI design with Guskey's evaluation framework, ensuring a systematic assessment of teacher learning, knowledge application, and student impact.

LITERATURE REVIEW

Professional Development

The evolving teaching and learning landscape require teachers to support students in acquiring complex 21st-century skills (Sancar et al., 2021). Effective teacher PDIs are crucial in bridging the gap between student learning demands and teacher practices. Darling-Hammond et al. (2017) identified vital attributes characterizing effective PDIs, such as a content focus, active learning, collaboration, modeling, coaching, feedback, and sustained duration. The present study specifically focuses on the content features of PDIs, emphasizing the integration of IK into science teaching. Sancar et al., in 2021, describe PD as a complex concept that evolves throughout a teacher's career, emphasizing context-oriented support. Frumin et al. (2018) highlight the positive impact of teacher collaboration on student outcomes, while Kelly et al. (2019) explored the integration of PD with curriculum planning. The complex nature of PD requires that teacher PDIs are designed on strong frameworks (Sancar et al., 2021) and constant evaluation to strengthen its effectiveness (Guskey, 2002). Guskey's (2002) evaluation framework helps evaluate the impact of PD on teachers and, by extension, on students.

Guskey's Evaluation Framework

Guskey's (2002) framework assesses PDI effectiveness by measuring teacher reactions, learning, institutional support, application of new knowledge, and impact on students. The framework informs the improvement of PDI in delivery and design; content, format, and organization; future change efforts; implementation of content; and overall impact of the PDI. Guskey's framework is a critical tool for assessing and improving PD in education (Acara and Erozanb, 2021; Firman et al., 2022; Ketelhut et al. 2020). Firman et al. (2022) emphasize its applicability in evaluating lesson study programs. Acara and Erozanb (2021) adapted Guskey's framework for assessing continuous PD events, stressing the importance of expert support and follow-up. Ketelhut et al. (2020) references Guskey's framework in the context of PDIs, emphasizing the need for teachers to test new methods in their classrooms actively. These studies highlight the framework's enduring relevance and versatility in evaluating and enhancing educational PD, emphasizing practical application, ongoing support, and meaningful changes in teaching practices. The present study employs Guskey's framework to assess the characteristics and challenges of teacher PDI supported by PCK evaluation.

Pedagogical Content Knowledge

PCK combines pedagogical and subject matter knowledge significantly improving student outcomes (Kind, 2019; Liepertz and Borowski, 2019; Pitjeng-Mosabala and Rollnick, 2018; Shulman, 1986; Sorge et al., 2019). Sorge et al. (2019) found that PCK development correlates with improved student outcomes as teachers integrate knowledge types. Pitjeng-Mosabala and Rollnick (2018) demonstrated that intensive PCK development enhances student outcomes. This study measures PCK by analyzing teacher portfolios in conjunction with the RTOP.

Reformed Teaching Practices as an Outcome of PDI's

The reformed teaching practices were measured using the RTOP (Piburn and Sawada, 2000). The RTOP assesses teaching practices and aligns with constructivist learning theories (Arifani and Hidayat, 2022). It reflects scientific inquiry principles and promotes active learning. Mantzicopoulos et al. (2018) confirmed its effectiveness, and Viskupic et al. (2019) found that PD improved instructors' RTOP scores. The RTOP is used in this study to assess teaching practices and provide insights into improving teaching, particularly regarding IK integration. The RTOP, developed as a standardized observation instrument, serves as an assessment tool for gauging reformed teaching practices. Effectiveness, defined by Smothers et al. (2022), revolves around a teaching approach that centers on the needs of the learners, fostering their basic psychological requirements and ultimately leading to comprehensive outcomes, including improved student achievement.

Indigenous Knowledge

IK encompasses culturally rooted understanding, values, and beliefs developed over time (Brondízio et al., 2021). South Africa's advocacy for IK integration aims to enhance teaching, learning, and sustainability by tapping into ancestral wisdom. Challenges arise from historical Euro-centric pedagogy and differences in nature and science perceptions between IK and Western-based science (Sekiwu et al., 2022). IK integration into science classrooms fosters holistic learning and catalyzes teachers' critical reflection on diversity and social justice (Kolb and Kolb, 2009). Miller Dyce and Owusu-Ansah (2016) found that targeted PDIs, combined with IK integration, empower teachers to embrace cultural diversity and adopt a transformative educational philosophy rooted in social reconstructionism. This interconnected approach highlights the transformative potential of diversity education, IK integration, and PDIs in shaping teachers' critical reflections and practices, further reinforcing holistic learning.

Various studies have explored IK integration challenges and solutions. These include curriculum development (Ndlovu et al., 2019), agricultural extension approaches (Radcliffe et al., 2021), didactic models (Zidny et al., 2020), teacher learning communities (Triyanto and Handayani, 2020), and the reliability of IK (Ankrah et al., 2022). Although, teacher views on the nature of indigenous knowledge (VNOIK) influence IK integration success (Cronje et al., 2015), Mavuru (2022) emphasized the need for teacher training to reimagine the utility value of IK, aligning with this study's focus on the PDIs impact on IK integration.

Views on the Nature of Indigenous Knowledge

The teacher's perspective on IK is shaped by their experiences, training in IK instruction, pedagogical knowledge, curriculum integration, limited science-based evidence, scarce literature, and perceived Western-IK conflicts. Inspired by Lederman et al. (2002), Cronje et al. (2015) devised the 10-question VNOIK instrument. De Beer (2022) and Litia (2018) employed a mixed-methods research approach with the VNOIK to explore the impact of PDIs. De Beer's study centered on integrating IK into classroom practices, while Litia's research focuses on teachers' evolving perspectives. These themes are central to the present study. While their methodologies align, the studies differ in contextual settings and specific research objectives. De Beer's work reveals challenges in sustaining post-PD changes, while Litia's study suggests limited shifts in teacher practices following teacher PDI.

The literature reviewed highlights the significance of PDIs, PCK, RTOP, and Guskey's evaluation framework in understanding and improving the integration of IK into science education. The study aims to assess the impact of PDIs on teacher practices and student outcomes related to IK integration, focusing on context-oriented support and teacher perspectives.

Financial Resources in Teacher PDIs

Financial resources are instrumental in shaping teacher PD within African educational contexts. The issue is that if we don't have funds you cannot provide relevant PD as you need experts to provide the interventions and is good to provide the teachers with tangible tools to take home and that also has financial implications. Du Plessis and Mestry (2019) underscore how poverty's dire influence stems from inadequate state funding, particularly in rural areas. This scarcity significantly obstructs teacher PDIs, leading to underqualified educators and multifaceted teaching practices rooted in both internal school structures and external factors, highlighting the critical role of financial resources. Building on this foundation, Myende et al. (2020) delve into the significance of efficient financial resource utilization in schools. Their research in Eswatini explores school principals' experiences participating in financial management-focused PDIs. These experiences underscore the pivotal role of financial resources in building effective financial management capacity, directly impacting PDI's success.

Moyo and McKenna (2021) expand the exploration, focusing on financial resources in higher education, particularly South Africa's University Capacity Development Grant. They emphasize the undifferentiated implementation of the Teaching Development Grant, which hinders institutions from allocating funds effectively to enhance teaching and learning. The need for context-based funding approaches is crucial in comprehensive teacher professional development. These studies underscore the paramount importance of financial resources in African teacher PD. Financial resources are foundational, whether through state funding, financial management training, or targeted grants. Inadequate or misallocated funds hinder PDIs, emphasizing the necessity for well-directed financial support to elevate educational standards and teacher quality across the continent.

CONCEPTUAL FRAMEWORK

The framework guiding the present study on assessing teacher PDI for integrating IK in science education is based on the concepts of PCK, reformed teaching, IK, and Guskey's evaluation framework. Figure 1 illustrates the conceptual framework used.

The direct measurement of PCK through teacher portfolios, reformed teaching using the RTOP instrument, VNOIK through questionnaires, and Guskey's evaluation framework allow for the identification of challenges to the process of IK integration. The characteristics of PD integration, derived from Guskey's 5-level evaluation framework, allow for the design of PDIs

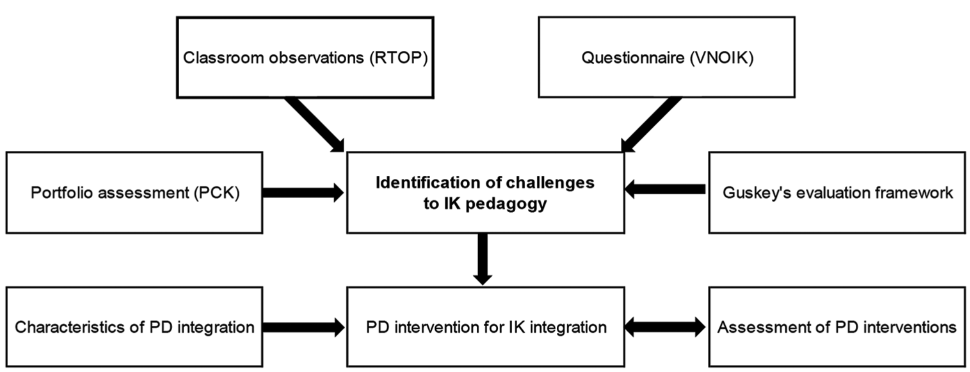

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Figure 1: Conceptual framework

in science education. The assessment of the designed PDIs serves as a feedback loop that continuously improves the PD design for the successful integration of IK in science. The exploration of TPD and its impact on teachers' understanding and integration of IK within the classroom developed four research questions that guide the study.

RESEARCH QUESTIONS

Through the identified characteristics of teacher PDI, the present study aims to illuminate the complex interplay between teacher PDIs, pedagogical practices, critical teacher reflection, and challenges in IK integration through the following research questions.

1. How do the observed challenges to IK integration inform the development of critical characteristics (design principles) for a science teachers PDI?
2. How do changes in teachers' understanding of IK, as observed through the VNOIK, correlate with their observed teaching practices in the classroom, particularly in terms of acknowledging IK, promoting conceptual understanding, and addressing IK effectively?
3. What role does critical teacher reflection play in aligning the teachers PD intended outcomes and the actual teaching practices in the classroom, and how does this evolve between Intervention 1 and Intervention 2?
4. How does the presence of a third partner (funders) impact the availability of tools (laboratory equipment) and teachers' ability to engage in meaningful laboratory inquiry work, and how does this relate to the effectiveness of the teacher PDI?

By addressing these research questions, the present study seeks to provide a comprehensive understanding of the characteristics and factors influencing the effectiveness of teacher PDIs in promoting IK integration, ultimately contributing to enhancing educational practices that respect and incorporate indigenous perspectives.

METHODS

The data collection process was structured to ensure a comprehensive assessment of teacher engagement and transformation. Semi-structured interviews with 62 teachers were conducted before and after the intervention to examine changes in their evolving perceptions of IK and instructional practices. The interviews were guided by a set of open-ended questions designed to capture teachers' conceptual understanding of IK, their perceived challenges in integration, and the impact of the PDI on their pedagogical decisions. Teacher portfolios were analyzed using the Saldana coding technique, which involved thematic analysis to identify patterns in instructional planning, resource utilization, and reflective practices. In addition, the RTOP was employed to evaluate the extent of instructional reform, focusing on lesson structure, student engagement, and inquiry-based learning. The VNOIK instrument assessed shifts in teachers' perspectives on IK before and after the intervention. Integrating PCK, VNOIK, and Guskey's evaluation framework into the analysis allowed for a multidimensional interpretation of the findings, ensuring that both conceptual and practical aspects of teacher learning were systematically addressed.

Research Design

Design-based research was followed as it allows for continuous improvement of an intervention (Sari and Herrington, 2013). After the face-to-face PDI, classroom observations were conducted with purposively selected teachers based on availability and locality. Lesson plans are manifestations of teachers' PCK and are indicators of professional learning, while observed classroom behavior is enacted PCK and counts as an indicator of teacher professional learning (Hume et al., 2020).

Sample

Two three-day, face-to-face interventions were carried out in two different regions of South Africa. Sixty-two science teachers participated in Intervention 1 and 37 science teachers participated in Intervention 2. The teachers that accepted the invitation participated voluntary.

Data Collection and Analysis

Table 1 presents a summary of the instruments used, the period of data collection, and the method of data analysis.

The VNOIK instrument (Cronje et al., 2015) includes a series of questions or statements that respondents answer to assess their beliefs, attitudes, or knowledge related to indigenous knowledge systems. Data were analyzed using the technique described by (Cronje et al., 2015) which links the VNOIK questions with the VNOIK framework. Quantitative analysis often includes summarizing responses using descriptive statistics, while qualitative analysis may identify patterns and themes in open-ended responses. Researchers may compare responses between different groups and interpret the findings in the context of their research objectives, ultimately reporting and discussing the implications of their results in research papers or reports. The answers to VNOIK items are scored 0 points for uninformed IK view, 1 for partial understanding, and 2 for an informed view on the nature of IK. The average score gauges respondents' IK perceptions, a higher average score corresponding to an enhanced VNOIK.

Table 1: Summary of instruments, data collection, and data analysis methods

Assessment	Instrument	Data collection	Data analysis
Teacher views	VNOIK and interviews	Before and after the intervention	Rubric
Classroom observation	RTOP	After the intervention and within 5 months	Five-point Likert scale
PCK	Teacher portfolios and interviews	Five months after the intervention	Saldana coding technique

The RTOP (Piburn and Sawada, 2000) measures the reformed teaching effort, comprising 25 5-point Likert scale items. The RTOP is divided into five subscales lesson design and implementation, propositional knowledge, procedural knowledge, student-teacher classroom interaction, and student-student classroom interaction. The RTOP instrument used in the present study is modified to include seven sub-scales comprising students' prior knowledge acknowledged; focus of lesson determined by learner ideas or inputs; lesson promoted conceptual understanding; students made predictions, estimations, and hypotheses; teacher's questions triggered divergent thinking; active participation by students; and IK effectively addressed. Each aspect of teaching evaluated by the RTOP is assigned a score on a scale from 0 to 4. A score of 0 means that this aspect never occurred during the observation, while a score of 1 implies that it occurred infrequently. If an aspect was observed to happen occasionally, it would receive a score of 2, while a frequent occurrence would merit a score of 3. Finally, a score of 4 indicates that this aspect was consistently observed throughout the evaluation.

Teacher portfolios included lesson plans on facilitation of IK in science, problem- and cooperative-based learning, and reflection on teaching. The portfolios were analyzed using the Saldana coding technique (Saldhana, 2021). Beginning with data collection, the process progresses with initial and open coding, where codes are applied to capture key concepts. In addition to constant comparison which aided in refining the coding structure, the present study employed a codebook to ensure consistency. The codebook provided a systematic and organized reference guide to conduct the qualitative coding and analysis. Themes and subthemes emerge as related codes are grouped, with data reduction condensing findings. Interpretation provides insights into the teacher's competencies and practices. Finally, the results are effectively communicated, presenting a cohesive picture of the portfolio's contents and significance.

Limitations

There are several limitations that deserve careful consideration. First, due to practical constraints, the restricted sample size may potentially hamper the generalizability of the findings. Moreover, while the insights gained are valuable, it is crucial to acknowledge that the findings may not universally apply to diverse educational contexts and could be region-specific. The reliance on self-reported data, including teacher reflections and questionnaire responses, introduces the possibility of response bias, highlighting the need for cautious interpretation. In addition, the observations of teaching practices are confined to a specific timeframe, which potentially hinders a comprehensive understanding of how these practices evolve over time. External factors such as curriculum changes, educational policy shifts, or resource allocation changes may confound the findings. The variability in the delivery and content of the PDI could have influenced how teachers responded. Given the wide range of teacher motivation levels, this factor might significantly impact their engagement with the PDI and the successful implementation of changes. Social desirability bias may influence how teachers modify their behavior or responses during observations or evaluations. Notably, the absence of a control group of teachers who do not participate in the PDI poses a challenge to attribute observed changes solely to the intervention. Future research should consider employing a larger sample size across varying educational contexts to provide a more comprehensive perspective.

Moreover, maintaining cultural sensitivity throughout the study, particularly concerning IK, is paramount. The present study may not have fully accounted for variations in resource availability across different school settings. Furthermore, the study's lack of differentiation between teachers with varying experience levels could impact their readiness to integrate IK effectively. A lower-than-expected response rate from participating teachers may affect data completeness and introduce potential bias. Finally, the timing of data collection concerning the PDI may have varied among participants, potentially influencing the measured outcomes. In light of these limitations, it is essential to approach the study's findings and conclusions with caution.

RESULTS

Intervention 1

Sixty-two teachers attended the first face-to-face intervention. Twenty-four teachers successfully attained the outcomes of the course and were awarded certificates.

Teacher portfolios

An example of a lesson plan from a teacher portfolio is shown in Figure 2.

School	School A*	**Grade**	11
Subject	Life Sciences	**Topic**	Biodiversity of plants and reproduction
Date	11 August 2016	**Duration**	60 minutes

Lesson topic	Differentiating between gymnosperms and angiosperms
Specific objective	Grouping gymnosperms into indigenous plants
Teaching and learning resources	*Understanding Life Sciences Grade 11* textbook as well as *Study and Master* textbook.
Teaching methods	Lecture and discussion

Activities	**Time**	**Teaching activities**	**Learner activities**
Introduction	10 min	1. Teacher ***explains**** what angiosperms and gymnosperms are. 2. Brief ***explanations**** on the type of plants which fall under the above-mentioned classification will follow. 3. Teacher ***explains**** what indigenous plants and animals are.	1. Learners ***listen**** and ***take notes**** 2. Discuss what they understand by indigenous knowledge. 3. Learners give examples of indigenous species found in their surroundings.
Presentation	45 min	1. The teacher ***explains*** the characteristics of gymnosperms. 2. Teacher ***informs*** learners to give examples of plants, which exist in their community and everyday life, which fall under this classification. 3. Teacher ***informs*** learners to give examples of plants, which exist in their community and everyday life, which fall under this classification.	1. Learners discuss in groups the characteristics of gymnosperms. 2. From their discussions, learners group the gymnosperms they know into indigenous plants they know. 3. From their discussions, learners list some angiosperms, which can be classified as indigenous species.
Conclusion	5 min	The teacher ***checks*** learners' work and ***summarises*** what was taught during the lesson.	Learners ***pay attention*** and ***give answers*** to arising questions.
Extended opportunities		Teacher helps learners.	Learners are given opportunities to ask questions and discuss what they have learned with one another and the teacher.
Reflection			

Figure 2: Intervention 1 lesson plan from teacher portfolio . School A* in Figure 2 refers to the transmission-mode approach in which the teacher explains to the learners in passive mode.

The lesson plan's specific objective refers only to indigenous plants and does not account for exotic gymnosperms and is indicative of the teacher's underdeveloped content knowledge. This lesson plan illustrates the tendency to teach-to-the-test and to use lectures rather than inquiry methods. Overall, this lesson plan is a poor attempt at infusing IK into the lesson. Very little evidence was provided of problem-based or cooperative learning approaches, which were emphasized during the PDI. After the face-to-face intervention, five lessons were observed.

Classroom observations

Table 2 provides an overview of the five lessons observed using the seven selected subscales of the RTOP instrument. The Likert scale used in the RTOP instrument is based on the following coding scheme: 0 = never occurred; 1 = seldom occurred; 2 = occasionally occurred; 3 = often occurred; 4 = occurred all the time.

Table 2: RTOP Analysis Intervention 1

Foci	Lesson				
	1	2	3	4	5
Students' prior knowledge acknowledged	1	0	1	1	0
Focus of lesson determined by learner ideas or inputs	1	1	1	2	1
Lesson promoted conceptual understanding	1	1	1	1	1
Students' predictions, estimations, and hypotheses	0	0	0	1	0
Teacher's questions triggered divergent thinking	0	1	0	2	1
Active participation by students	1	1	1	3	1
Indigenous knowledge effectively addressed	1	0	1	2	1

Table 2 shows that Lessons 2 and 5 acknowledged students' prior knowledge, demonstrating an awareness of their existing understanding. Regarding the focus on learner ideas or inputs, all lessons displayed some level of attention to this aspect. Lesson 4 was the most learner-centered, followed by Lessons 2, 3, 4, and 1. One consistent strength across all lessons was the promotion of conceptual understanding, indicating a robust commitment to this fundamental principle of reformed teaching. However, students' engagement in making predictions, estimations, and hypotheses varied, with Lesson 4 being the primary lesson where students actively participated in these cognitive processes. Teacher questions were pivotal in triggering divergent thinking among students, with Lesson 4 again taking the lead. Lesson 2 also exhibited a degree of effectiveness in this area, while Lessons 1, 3, and 5 featured fewer such thought-provoking questions. Active student participation, a cornerstone of reformed teaching, was most pronounced in Lesson 4, followed by Lessons 2, 3, 5, and 1, demonstrating varying levels of student involvement in the learning process.

The effective addressing of IK needs to be more consistent across the lessons. Lessons 3 and 5 emerged as examples where IK was effectively integrated into the teaching, while Lesson 4 moderately addressed it. In contrast, Lesson 1 minimally or not at all, and Lesson 2 needed to address IK effectively. These observations revealed that while all lessons consistently promoted conceptual understanding, there were differences in their approaches to acknowledging prior knowledge, focusing on learner ideas, engaging students in divergent thinking, and fostering active student participation. In addition, the effective incorporation of IK varied across the lessons. Lesson 4 emerged as a notable exemplar of reformed teaching, emphasizing active student engagement and using divergent thinking-triggering questions. The data indicate a low level of reformed teaching.

Teacher views on IK integration

The pre- and post-VNOIK were investigated before and after Intervention 1 (Table 3).

Table 3: VNOIK Responses Intervention 1

Participant view (N=62)	Pre-VNOIK	Post-VNOIK
Uninformed view	5	0
Partially informed view	50	34
Informed view	7	28

Table 3 shows that pre-intervention, 8% of the teachers presented an uninformed view of IK, 81% presented a partially informed view of IK, and 11% presented an informed view of IK. After the intervention, none of the teachers presented an uninformed view. In contrast, 55% of the teachers presented a partially informed view of IK, and 45% presented an informed view of IK. The intervention successfully informed teachers of IK.

Challenges identified and PDI redesign

Teacher portfolio and the VNOIK questionnaire analysis revealed that teachers exhibited limited content knowledge and struggled with pedagogical approaches related to IK. Their teaching often reverted to traditional transmission-mode methods, characterized by chalk-and-talk approaches and textbook reliance. Explorations into alternative pedagogies and using cost-effective materials for inquiry-based learning needed to be more robust. Second, despite teachers developing a more nuanced understanding of IK (as demonstrated through the VNOIK questionnaires), integrating IK into the science classroom must be more adequately reflected in their portfolios and observed lessons. The incorporation of IK into science education, utilizing scientific processes and tenets, needed to be developed more. Finally, teachers' portfolios revealed limited evidence of learning through reflection, with their reflections often appearing superficial, signaling a lack of regular reflective practices in their teaching.

In response to these findings, Intervention 2 introduced several vital improvements. Recognizing the challenge of swiftly addressing teachers' deficient content knowledge in IK, the intervention provided additional resources, including modified workshop materials and extra textbooks, to bridge the knowledge gap. To promote the fusion of IK and science, educators were instructed on harnessing the potential of IK systems. This approach aimed to bridge the gap between IK and scientific practices.

Furthermore, efforts to enhance self-directed learning through reflection were made by incorporating opportunities for reflection within the face-to-face intervention and introducing elements of classroom action research to improve teachers' reflection skills. Finally, the analyzed lesson plans indicated a lack of teaching and learning materials that negatively impact this epistemological border-crossing. Therefore, to bolster systematic resource provision, a partnership was established with funders to equip teachers with the necessary tools and resources for their classrooms, enhancing inquiry-based learning and laboratory work. These strategic adjustments were geared toward addressing the identified limitations and enhancing the overall effectiveness of the PDI, ultimately promoting a more comprehensive integration of IK into science education.

Intervention 2

Thirty-seven teachers attended the second face-to-face intervention. Twenty-seven teachers successfully attained the outcomes of the course and were awarded certificates.

Teacher portfolios

The portfolios submitted after Intervention 2 provided more evidence of problem-based and cooperative learning strategies, more creativity was seen. However, in both interventions, there were limited examples of effective infusion of IK into lesson plans. An example of a teachers' lesson plan illustrates a creative way of integrating IK into a difficult lesson topic, DNA technology (Figure 3).

Lesson topic **Duration**	DNA technology: Extracting DNA from plant tissue 90 minutes
TEACHER'S ACTIVITIES	**LEARNERS' ACTIVITIES**
Introduction I will ask learners to provide examples of how DNA technology finds application in our everyday lives.	Learners will discuss the application of DNA technology in small groups and be encouraged to Google information on their cell phones. After ten minutes, groups will provide feedback.
Consolidation of learners' feedback Based on learners' feedback, I will provide a short overview of application of DNA technology (e.g., DNA barcoding), such as the authentication of medicinal and herbal products, invasive and alien species, and wildlife crime.	A question-and-answer session, in which learners will be allowed to think of examples of these applications – e.g., examples of wildlife crimes (e.g., rhino poaching).
Contextualising the lab activity I will provide the following background to this lab: From time to time, patients die when they take the medicines given to them by traditional healers. It is therefore necessary sometimes to do DNA barcoding to determine what plant and animal species have been used in making these traditional medicines. Today we are going to extract DNA from bananas. I will utilise a "shoestring approach", where learners will extract DNA from plant materials such as bananas. Learners will need laboratory beakers, water, filter paper, salt, dishwashing liquid, a bit of ethanol, pineapple juice and a fork. Although I will provide learners with the steps to follow in the procedure, I will prompt them to think about every step. E.g., why do we crush banana tissue in a strong salt water? What is the role of the alcohol and detergent? Learners will study the extracted DNA with magnifying lenses. Learners will be asked to answer questions – some of them on higher levels in Bloom's taxonomy – e.g. What would have happened if the banana tissue was placed in water of 70 degrees Celsius?	Learners engage in practical work in the laboratory
Assessment (Lab report) Learners will be asked to do the lab report in a different way, namely in the form of an article for a scientific journal.	Learners are asked first to study a few examples of journal articles and then, in their small groups, to plan and write an article. Apart from explaining the lab procedures, emphasis should be placed on how this technology is applicable in everyday life.

Figure 3: Intervention 2 lesson plan from teacher portfolio

The portfolio analysis for Intervention 2 revealed increased creativity among teachers, notably through innovative approaches like integrating IK into challenging subjects, such as DNA technology. This approach emphasizes the practical relevance of science in daily life, even without access to computers. Teachers also posed compelling questions, such as addressing patient poisoning with traditional medicines in South Africa, showcasing IK's classroom relevance. These strategies offered a refreshing departure from traditional teaching methods, reflecting the adaptability required in modern education.

Classroom observations

Table 4 provides an overview of the five lessons observed using the seven selected subscales of the RTOP instrument.

Table 4 presents the analysis of lessons across various foci, shedding light on the effectiveness of pedagogical approaches. Notably, Lessons 2 and 4 stand out for recognizing students' prior knowledge, earning a high score of 3. This acknowledgment of existing knowledge can be instrumental in facilitating effective teaching. However, there is a general trend across all lessons toward a moderate score of 2 regarding the lesson's focus being determined by learner ideas or inputs, suggesting that there is room for improvement in incorporating student input into lesson planning. On the bright side, all lessons consistently score a 2 for promoting conceptual understanding, indicating moderate but consistent effectiveness. Lesson 4 encouraged students to make predictions, estimations, and formulate hypotheses (score of 3), as well as trigger divergent thinking through the teacher's questions (score of 3). These elements are crucial for nurturing critical thinking and creativity. Active student participation is notably high Lessons 2 and 4 (score of 3), a vital factor for an engaging learning environment. Furthermore, addressing IK is effectively accomplished in Lessons 2, 4, and 5, highlighting the importance of cultural relevance and inclusivity in education. The RTOP analysis of Intervention 2 underscores the diverse strengths and areas for improvement in the assessed lessons, providing valuable insights for pedagogical enhancement.

VNOIK questionnaire

The VNOIK was investigated before and after Intervention 2, and the results are shown in Table 5.

Table 5 shows that almost 3% of the teachers presented an uninformed view of IK, 76% presented a partially informed view of IK, and 22% presented an informed view of IK. After the intervention, none of the teachers presented an uninformed view. In contrast, 24% of the teachers presented a partially informed view of IK, and 76% presented an informed view of IK. The intervention successfully informed teachers of IK.

Challenges identified and PDI redesign

Significantly, 60% of the portfolios within Intervention 2 shifted from conventional transmission-mode teaching to more interactive problem-based and cooperative learning approaches. Educators actively engaged students in scientific

Table 4: RTOP Analysis Intervention 2

Foci	Lesson				
	1	2	3	4	5
Students' prior knowledge acknowledged	2	3	2	3	2
Focus of lesson determined by learner ideas or inputs	2	2	2	3	1
Lesson promoted conceptual understanding	2	2	2	2	2
Student's predictions, estimations, and hypotheses	1	2	2	3	2
Teacher's questions triggered divergent thinking	2	2	2	3	2
Active participation by students	2	3	2	3	2
Indigenous knowledge effectively addressed	3	3	2	3	3

0=never occurred; 1=seldom occurred; 2=occasionally occurred; 3=often occurred; 4=occurred all the time.

Table 5: VNOIK Responses Intervention 2

Participant view (N=37)	Pre-VNOIK	Post-VNOIK
Uninformed view	1	0
Partially informed view	28	9
Informed view	8	28

projects, such as water quality investigations, aligning with the need for comprehensive resources to support such initiatives. The disparities observed in integrating IK and alignment with scientific principles across the two interventions have become evident. Within Guskey's framework, adjustments were noted in teacher learning (Level 2) and the application of acquired skills (Level 4) in response to these considerations.

Furthermore, the emphasis on self-directed learning through reflection led to more profound and nuanced reflections among participants. This transformation aligns with the evolving expectations within Guskey's Level 2. Finally, the availability of funding enhanced the provision of systematic resources to teachers. This practical approach supports cost-effective water analysis and signifies a progression within Guskey's Level 3.

These characteristics underscore the pivotal role of meticulous planning and comprehensive support when designing PDIs to seamlessly integrate IK into science teaching. Such an approach ensures meaningful professional development and culminates in enriched classroom practices.

DISCUSSION

The findings of this study contribute to the broader field of science teacher education by demonstrating the pivotal role of well-structured PDIs in fostering pedagogical transformation and cultural responsiveness. The results indicate that sustained engagement with IK-focused PDIs enhances teachers' ability to contextualize science instruction, making learning more meaningful and inclusive. This study's findings have far-reaching implications for multiple stakeholders, including policymakers, curriculum designers, and educators. Policymakers should prioritize funding and policy support for long-term PDIs incorporating IK, ensuring teachers receive ongoing training, mentorship, and access to culturally relevant teaching resources. Curriculum designers should collaborate with IK holders and science education researchers to develop instructional materials that seamlessly integrate IK with core science concepts. Educators, in turn, should engage in reflective practices and professional learning communities to refine their approaches to IK integration continuously. By embedding these strategies within science teacher education programs, institutions can promote culturally sustaining pedagogies that enhance student engagement and scientific literacy in diverse educational settings. These insights provide a deeper understanding of how PDIs shape teachers' knowledge, instructional practices, and the support of effective integration of IK into science education.

How do The Observed Challenges to Ik Integration Inform The Development of Critical Characteristics for A Science Teachers Pdi?

The observed challenges to IK integration comprise teachers' content knowledge and pedagogical approaches to IK, border-crossing between IK and science, self-directed learning through reflection, and systematic resource provision. These challenges identify critical characteristics of science PDIs for IK integration. Using the critical features of effective PD (Darling-Hammond et al., 2017), it emerged that other characteristics should be kept in mind when planning PDIs to integrate IK into science teaching. These characteristics are a theoretical framework for adult learning, pedagogical approaches to the integration of IK into science, self-directed learning through reflection, and systematic resource provision.

1. How do changes in teachers' understanding of IK, as observed through the VNOIK, correlate with their observed teaching practices in the classroom, particularly in terms of acknowledging IK, promoting conceptual understanding, and addressing IK effectively?

The correlation between changes in teachers' understanding of IK and their classroom practices is critical to the study. While the VNOIK questionnaire results show a positive shift in teachers' knowledge, implementation of this knowledge in their teaching practices presents some complexities. The classroom observations reveal a mixed picture, with some improvements noted in Intervention 2 compared to Intervention 1. Teachers in Intervention 2 were more likely to acknowledge IK in their teaching and promote conceptual understanding. However, the effectiveness of addressing IK remained inconsistent. This inconsistency suggests that although teachers may have developed a deeper understanding of IK, translating this understanding into effective teaching strategies is challenging. Factors such as systemic pressures and curriculum pacing rules may hinder their ability to integrate IK into their lessons fully. Therefore, the study highlights the need for ongoing support and guidance to bridge the gap between teachers' improved understanding and classroom practices.

2. What role does critical teacher reflection play in aligning the teachers PD intended outcomes and the actual teaching practices in the classroom, and how does this evolve between Intervention 1 and Intervention 2?

Critical teacher reflection emerges as a key factor in bridging the gap between the intended outcomes of the teacher PDI and actual classroom practices. In Intervention 1, despite some teachers agreeing to adopt problem-based and cooperative learning approaches during the PDI, there was limited evidence of sustained implementation in the classroom. However, in Intervention 2, teachers were more willing to embrace these approaches and effectively transfer competencies to their teaching practices.

This shift can be attributed to teachers' increased engagement in critical reflection. An excerpt from a teacher's portfolio, "I think IK should be the starting point of the technological process and should be included in the situation analysis," indicates that teachers started to recognize the value of problem-based and cooperative learning methods and the significance of incorporating IK. This evolution highlights the importance of creating opportunities for ongoing reflection and PD to facilitate meaningful changes in teaching practices.

3. How does the presence of a third partner (funders) impact the availability of tools (laboratory equipment) and teachers' ability to engage in meaningful laboratory inquiry work, and how does this relate to the effectiveness of the teacher PDI?

The presence of external partners, in this case, funders, plays a pivotal role in influencing the availability of resources, particularly laboratory equipment. In Intervention 2, there was a noticeable improvement in the availability of tools, which allowed for more meaningful laboratory inquiry work in the classroom. This positive development is linked to the involvement of external funders who provide the necessary resources. The availability of laboratory equipment is essential for implementing problem-based and cooperative learning approaches and effectively infusing IK into science lessons. The finding suggests that external partnerships can significantly enhance the effectiveness of teacher PDIs by providing the essential tools and resources needed to facilitate innovative teaching practices.

CONCLUSION

The interviews with teachers and the analysis of teacher portfolios, RTOP, and VNOIK revealed that a practical approach to integrating IK into the science curriculum involves providing PD opportunities. These PD opportunities enable teachers to enhance their teaching practices, fostering reflection and the practical application of acquired knowledge within their professional contexts. The findings highlight several critical considerations for improving PDIs within IK integration in science education. Reflection on the factors influencing Intervention 2 and the framework proposed by Guskey (2002) highlights the need for adjustments in PDIs. These adjustments encompass a range of aspects, including teachers' content knowledge and pedagogical approaches related to IK, the seamless intersection of IK and science, the promotion of self-directed learning through reflection, and the provision of systematic resources. The present study's findings, which align with Sancar et al. (2021), suggest that PDIs are more successful when based on a robust framework, highlighting that limited knowledge of teacher PDIs may hinder the attainment of its intended objectives. When examining the critical characteristics essential for the successful integration of IK into science PDIs, four fundamental factors emerge, derived from the project's experiential learning rather than directly from the data:

1. Grounding PDIs in a solid theoretical framework is the foundation for crafting effective initiatives.
2. Emphasizing specific pedagogical approaches that address the central challenge of IK integration enhances the potential for substantial improvements in teaching practices.
3. Encouraging self-directed learning through reflection empowers teachers to set professional development objectives and systematically evaluate outcomes, aligning with the dynamic landscape of teacher growth.
4. Establishing systematic resource provision not only financially but also through collaborative efforts with museums, IK holders, and educational institutions to enable contextualized learning opportunities and strengthen the overall impact of PDIs, effectively catering to the diverse needs of educators and learners.

These findings underscore the need for tailored adjustments in PDIs to integrate IK into science education seamlessly.

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