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In-Service Science Teacher Professional Development Effective Strategies: 2020 to 2025

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Abstract

This article systematically explores professional development (PD) strategies for secondary education science teachers from 2020 to 2025, analyzing 38 studies using PRISMA guidelines. Key findings include publication trends and common PD strategies, with 17 strategies categorized. Collaboration, assessment, evaluation, pedagogy, content, and technology are the most frequently mentioned. The study highlights the importance of these strategies in enhancing teaching practices and student outcomes. Future research should focus on emerging trends, long-term impacts of professional development interventions, and effective strategies to address the evolving needs of science teachers in a rapidly advancing educational landscape.

Keywords: Professional Development Strategies, Science Teacher, Secondary Education, in-Service, Systematic Literature Review

Introduction

The intensification of global competition is a direct consequence of increasing globalization and rapid advancements in science and technology (Ye, Mi & Bi 2021). The progress of science and technology is closely linked to the support of science education (Almuraie, Algarni & Alahmad 2021). As society increasingly embraces technological advances, there is a growing demand for the integration of science education into broader educational goals (Musa, 2020). This responsibility falls on in-service science teachers to develop the next generation of students and meet the expectations of a science and technology powerhouse.

Therefore, prioritizing the professional development (PD) of science teachers, particularly in the field of science education, becomes crucial (Lewis, 2023). Effective planning for the PD of science teachers and synthesizing successful strategies and approaches are necessary to achieve the ultimate goal of enhancing teacher performance (Aldahmash et al., 2019; Darling-Hammond & Richardson, 2009; Hofstein et al., 2005). Despite the recognized

importance of PD, there is a lack of comprehensive strategies specifically tailored to the unique needs of in-service science teachers (Aldahmash et al. 2019). This gap in the literature highlights the need for a systematic investigation into effective PD strategies.

Techers' PD can be categorized into two main types: traditional and innovative (Sancar, Atal & Deryakulu 2021). Traditional PD primarily consists of structured processes and activities aimed at enhancing teachers' professional knowledge, skills, and attitudes to improve student learning (van Driel & Berry 2012; Guskey 2002; Nilsson & van Driel 2010). However, this approach often views PD as a one-size-fits-all solution, which may not address the specific needs of individual teachers or adapt to the dynamic nature of educational environments (Al-Shehria & Gharamah 2021; Coldwell 2017)

In contrast, innovative PD places greater emphasis on the teacher themselves. considering their needs, goals, aspirations, emotions, motivations, and dreams (Korthagen 2017). This approach defines PD as the process of accumulating skills, professional knowledge, values, and personal qualities (Kennedy 2016; Korthagen 2017; Ye & Bai 2001). Innovative PD is more flexible and personalized, potentially leading to more meaningful and lasting improvements in teaching practices.

Desimone (2009) summarized five general characteristics have emerged as effective in PD: (i) specific content focus (Darling-Hammond, Hyler & Gardner 2017; Frågåt 2021; Garet 2001; Guskey 2003; Loewenberg Ball & Cohen 1996), (ii) involving teachers in active learning (Garet 2001; Loucks-Horsley 1996), and (iii) enabling the collective participation of teachers (sometimes administrators) (Desimone 2009; Garet 2001), and (iv) coherence (alignment with other school policies and policy and practice) (Desimone 2009) and (v) sufficient duration (both in terms of intensity and contact hours) (Guskey 2002; Loewenberg Ball & Cohen 1996; Supovitz & Turner 2000).

In recent years, the continuous development and innovation in science and technology have allowed for the integration of technology into the classroom (Bumagat et al. 2023). Particularly for abstract scientific concepts, technology enables students to see scientific phenomena more clearly and intuitively, enhancing their understanding (Akun & Mohamad 2021; Dai Lingling & Lu Qingguang 2023) and increasing their interest (Zhang 2023). Given that teachers' PD is dynamic (Zhu Min 2019), the use and mastery of technology have gradually become essential aspects of their professional growth ((Büyükbayraktar, Karamustafaoğlu & Özdoğan 2022). This evolution ensures that teachers can effectively incorporate new tools and methods into their teaching practices, thereby enhancing the learning experience for their students.

A thorough literature review revealed that few studies focus on strategies for the professional growth of in-service science teachers (Aldahmash et al. 2019). Therefore, it is necessary to develop PD strategies and implement training programs aligned with global trends and changes in the socio-economic landscape to equip teachers with the necessary skills and experiences to fulfill their primary roles in the educational process.

This highlights the crucial importance of adapting PD approaches to address the evolving needs and challenges faced by science teachers in today's educational context, thus

contributing significantly to the enhancement of educational outcomes and societal progress. Therefore, we conducted a systematic study of PD strategies for in-service physics teachers, aiming to solve the following problems:

- What are the trends in teacher professional development strategies in 2020-2025?
- What are the current professional development strategies for in-service science teachers?
- Which professional development strategies are more mainstream?

Materials and Methods

This study utilized the Systematic Literature Review (SLR) method to examine existing literature on effective strategies for the PD of science teachers in secondary education from 2020 to 2025. The systematic review was conducted following the PRISMA guidelines.

Literature Search

The literature search was conducted using the ERIC database. The primary search terms included: "Professional Development" OR "Professional Growth" OR "Professional Training" AND "Strategy" OR "Way" OR "Approach" OR "Method" AND "Science teacher" AND "Secondary education" OR "Secondary School" OR "High School" OR "Middle School" OR "Middle education" OR "Junior High School" OR "Upper Secondary Education" OR "Comprehensive School." This search yielded 38 relevant articles on professional development strategies for science teachers.

Data Collection Procedures

The systematic review was conducted following the PRISMA guidelines. The selected articles met the following criteria: (a) written in English; (b) published from 2020 onward; (c) focused on secondary education; (d) published in peer-reviewed journals with full text available; (e) involving novice teachers; and (f) focused on the professional development of science teachers (Table 1).

Table 1
The Eligibility and Exclusion Criteria

Criterion	Eligibility	Exclusion
Literature	Peer-reviewed Journal	Book, book series, chapter in a book, systematic review articles, and conference proceeding.
Language	English	Non-English
Timeline	Between 2020-2025	Before 2020
Grade	Secondary education	Primary, higher education
Subject	Science novice teacher	Subjects other than science

The study excluded all duplicate articles, those outside the scope of secondary education and science teacher studies, and those involving pre-service teachers. Articles that did not relate to teachers' PD were also excluded. After these exclusions, 38 articles were included in this review. The selection process is illustrated in Figure 1

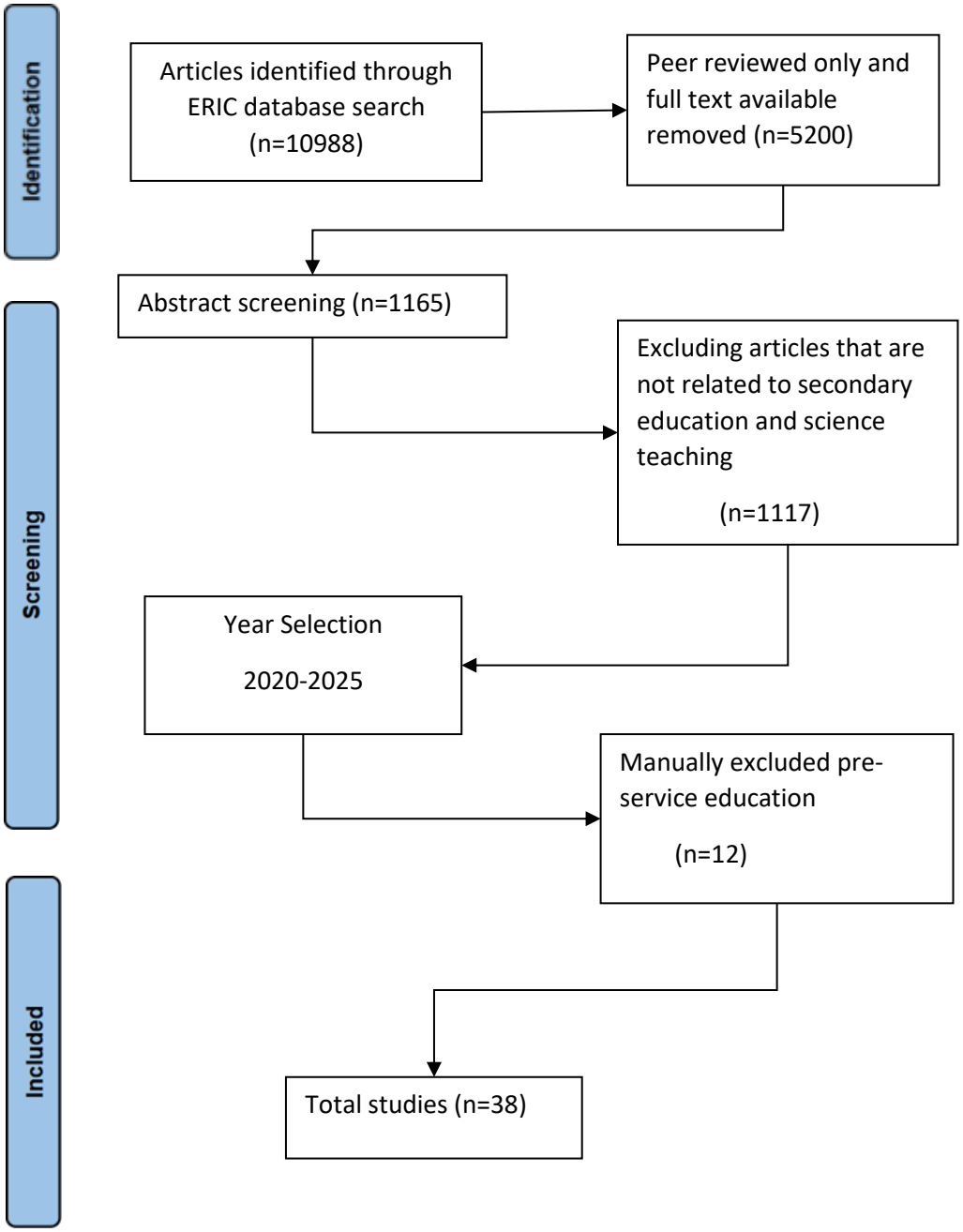

Figure 1. Flow chart of study selection process based on PRISMA

Ethical Considerations

Since this study is a systematic review of existing literature, no ethical approval was required.

Result

Understanding publishing trends is crucial for determining the progress of a given field. Between 2020 and 2025, a significant number of studies on PD strategies for in-service teachers were published. A systematic review was conducted to select relevant articles, and ultimately, 38 articles were included. Table 2 illustrates the teacher PD strategies mentioned in these articles by year.

Table 2
Strategies of Professional Development

Publish year	Strategies of PD involved	Publish year	Strategies of PD involved
2020	• Reflective Practice; • Communities of Practice; • Critically evaluating; • Design and plan Lesson; • Multiple perspectives; • Workshop; • Mentor.	2020	Effective Teachers and Effective Teaching program.
2020	Socio-Scientific Issues (SSI) PDPs.	2020	Seminars, Workshops and Information Access.
2020	• Mentor relationships; • Self - reflection • Classroom Management • Instructional Strategies • Co – Curricular Activities	2021	Organizing well-planned in-service trainings to increase the teaching motivation.
2021	Train-the-trainer biology workshop (TTTBW) • Effective communication skills for biology teaching; • Teaching management skills; • Dynamics of child education; • New pedagogical skills in teaching Biology; • Strategies for targeted Assessment in Biology; • Adaptation of Biology teaching for resource-poor countries.	2021	• Developing and improving the use of technology for teaching activities; • Developing critical thinking and problem solving skills of students; • Developing teamwork skills in-class and out-of-class activities; • Development of meaningful context-based learning; • Development of teaching methods within the scope of pedagogical content knowledge.
2021	Using Virtual Reality (VR) technology in the class.	2021	Receiving distance learning training and improving technology facilities.
2021	Guide teachers' PD around teachers' understanding and acceptance of STEM requirements.	2021	Key teaching competencies.
2021	Teachers collaborating and reflecting on their planning of lessons and teaching.	2021	Encourages use of available e-learning facilities and in-service training.
2021	• Providing biology teachers with modern basic scientific knowledge in the field; • Providing in-service training programs; • Providing PDPs;	2022	Improving the efficiency and effectiveness of people in service is accomplished via the organization of in-service training (IST) programs aimed at enriching

Publish year	Strategies of PD involved	Publish year	Strategies of PD involved
	• Encouraging teachers to use modern methods.		their knowledge, abilities, and attitudes. • Teaching technologies; • Tools; • Materials suitable for physics instruction; • Identifying students' individual differences and establishing level groups; • Modern physics in technology.
2022	• Intensive language training; • Guidance of foreign experts; • Mentoring system; • Organization of Content and Language Integrated Learning (CLIL) courses abroad; • Online courses; • Sharing good practices; • Cooperative work.	2022	Integration of Visual Arts elements in STEM could ease various pedagogical challenges which include students' thinking ability, practical knowledge, and ability in technology; constraints related to teaching aid and ensuring student understanding of "difficult" topics in the lower secondary Science syllabus.
2022	Offer the Newly Qualified Teachers (NQTs) the opportunity. • Link with expert teacher educators for collaboration; • Experience and knowledge sharing; • Clearing doubts; •Gaining understanding of different pedagogies.	2022	• Importance of hard work; • Collaboration; • Curious and Scientific Attitude
2022	Developing formative assessment as a teaching tool in science teaching.	2022	Argumentation-based Inquiry training.
2022	• Mentored by backbone teachers; •High-quality lesson competitions; • The support of families and schools; • Constantly learning; • Continuously engaged; • Self-reflection; • Synthesizing.	2022	• Appropriate identification and use of instructional materials; • Application of skills and competencies needed for teaching and learning; • Application of appropriate assessment strategies of learners' progress in the classroom and adequate knowledge of the subject

Publish year	Strategies of PD involved	Publish year	Strategies of PD involved
			matter.
2022	Game based learning.	2022	Socio-Scientific Issues training.
2023	Enacting TSPCK in respiration during a lesson study • Collaborative planning; • Teaching; • Reflecting on the teaching.	2022	• Problem-Based Learning; • Self-Directed Learning; • Blended Problem-Based Learning.
2022	Guiding the science teachers in choosing their preferred arrangement of content of the new Science spiral curriculum.	2022	Online self-assessment instruments (OSISDeP) to measure the teachers' Knowledge, Attitudes, and Behaviors (KAB).
2023	Useful instrument to assess the practical knowledge of teachers in practical work.	2023	• Self-efficacy • Innovative teaching; • Comprehensive teaching approach
2023	• Project studies • Project studies out-of-school studies •Teaching science collaborative learning • Developing self-efficacy.	2023	Nature of Science course • Nature of science: definitions; Views of science, science as a body of knowledge, a way of thinking, a way of investigating; • Instructional strategies: integrating historical cases into science teaching; NOS-focused lesson-planning; • Structured small-group discussions; • Structured reading; • Listening to or watching stories about past and present scientists.
2024	• Centering on inquiry-based teaching ; • Group collaborative learning, • Role rotation ; • Providing workbooks containing experimental methods, apparatus, and steps ; • Conducting diverse scientific investigation activities ;	2024	• learning and renewal skills, life and career skills, information, media and technology skills) • STEM attitudes (with 2 sub-dimensions: • STEM activities, lesson planning), supplemented by semi-structured interviews for qualitative data;

Trends in Teacher Professional Development Strategies In 2020-2025

A visual data depiction shows changes in the number of published articles from 2020 to 2025. From 2020 (6 articles), the count rose, hitting a peak in 2022 with 14 articles — a sign of surging interest in the subject matter. But in 2023, it dropped back to 6, hinting at a possible

shift in research priorities. By 2024, it further declined to 2, and 2025 data is absent. Still, the overall pattern highlights the topic's enduring importance during these years, even with the fluctuations.

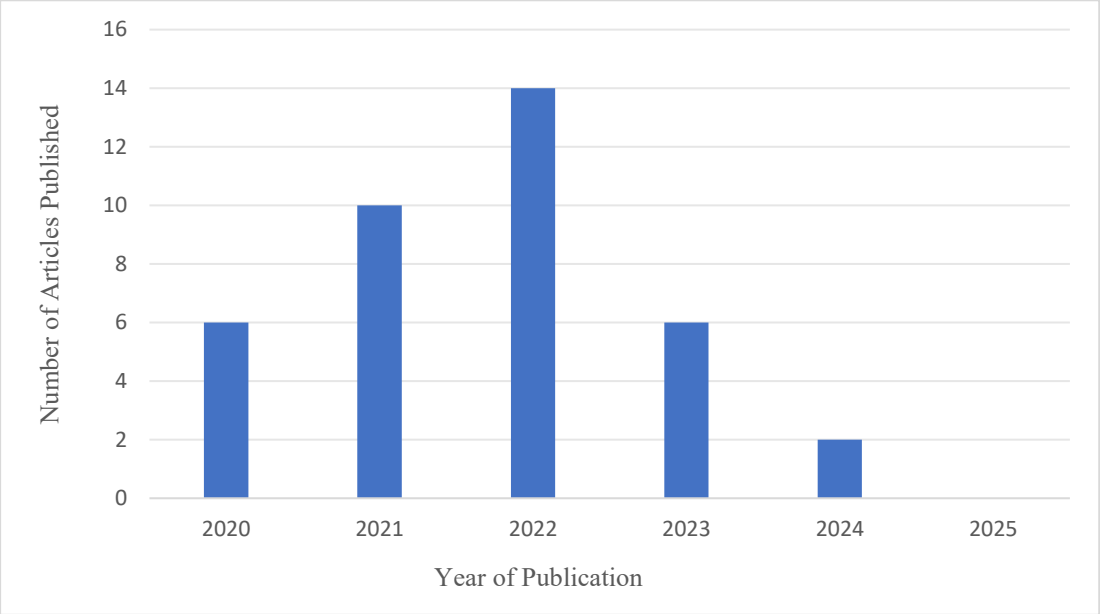

Figure 1. Distribution of the Number of Articles on Science Teachers' PD Strategies from 2020 to 2025

Current professional development strategies for in-service science teachers

A total of 38 articles describe various types of teacher PD strategies. It is evident that the views expressed in multiple articles overlap. To gain a more comprehensive and clearer understanding of existing teacher PD strategies, these strategies have been classified by the authors into 17 categories as shown in Figure 3.

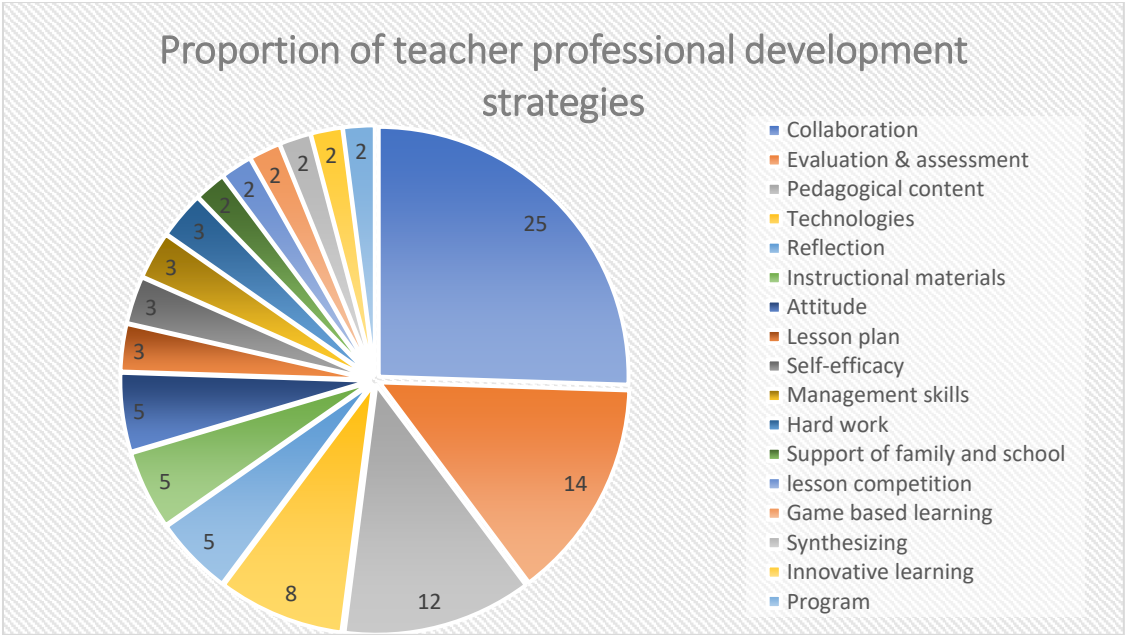

Figure 3 Proportion of teacher professional development strategies

Discussion

Collaboration is a crucial means of facilitating teachers' PD (Minken et al. 2021; Naudé & Pretorius 2024). As shown in the pie chart, collaboration strategies were referenced in 26% of the articles reviewed, making it the most frequently mentioned strategy among those pertaining to teacher PD. This underscores the significance of collaboration in the PD process. Engaging in collaborative activities allows teachers to share experiences, obtain feedback, communicate, and work with their peers, thereby collectively enhancing teaching standards (Naudé & Pretorius 2024; Tekin, Aslan & Keleş 2023). The importance of collaboration is evident as it plays a central role in the teacher learning process over the duration of PD (Minken et al. 2021). This article categorizes collaboration into three distinct categories: workshops, communities of practice, and mentor systems. However, further exploration is needed on how schools arrange experienced teachers to help new teachers with their PD and how to maintain a good relationship with their mentors (Whalen, Majocha & Van Nuland 2019). This indicates a gap in current PDPs that future research should address.

Assessment and evaluation strategies in PD are crucial for enhancing teaching practices and educational outcomes (Bin et al. 2023). As shown in the pie chart, these strategies are referenced in 14% of the articles reviewed. These strategies, referenced in 14% of the articles reviewed, serve multiple functions by integrating various assessment methods into the curriculum, evaluating teachers' abilities, skills, and knowledge (Payne et al. 2019). This continuous feedback loop is essential for professional growth. Properly used, assessments inform instructional practices, identify areas needing attention, and ensure targeted interventions, ultimately improving student outcomes (Yousef & Abduh 2021), However, the effectiveness depends on the quality of data and the ability to interpret it (Zhai, Krajcik & Pellegrino 2021). Future research should focus on improving the reliability and interpretation of assessment data.

Curriculum and pedagogy development represent key components of teacher PD (Minken et al. 2021; Naudé & Pretorius 2024). This theme recurs in 12% of the articles, highlighting the need for teachers to continuously update course content and teaching methods to adapt to changes in student needs and educational development (Wang Yuechan 2021), espite its importance, few studies have delved into teachers' perspectives on curriculum content, especially as science curricula undergo changes (Degorio, 2022). Addressing this gap could lead to more effective curriculum development strategies.

The increasing popularity of the Internet, information technology, and multimedia has led to the emergence of new approaches to teacher development and education (Jang, 2014). The emergence of virtual reality (Christopoulos, Conrad & Shukla 2018), augmented reality, and holographic technologies has brought about changes in the way teachers are trained and developed. While science learning can sometimes be abstract (Akun & Mohamad 2021; Dai Lingling & Lu Qingguang 2023), the integration of science and technology provides teachers and students with a framework for understanding knowledge more concretely (Bumagat et al. 2023). This, in turn, facilitates student acquisition of knowledge while concomitantly enhancing overall student engagement and interest in the integrated classroom (Celik 2023; Rutten, Van Joolingen & Van Der Veen 2012). In particular, for science teachers, the display of virtual platform technology has become a more pivotal component of teachers' PD

strategies (Zhang & Tang 2021). Nevertheless, mentions of technology only constituted 8% of articles from 2020 to 2023. Further development in this area is therefore required.

Reflection, instructional materials, and attitude are each mentioned in 5% of the total strategies. Reflection enables teachers to critically assess and improve their teaching practices, leading to better student outcomes and a more adaptive teaching environment. By continuously evaluating their methods, teachers can implement effective changes that enhance learning experiences (Mathew et al. 2017). Engaging with curriculum and instructional materials allows teachers to critically analyze and adapt them, which is enhanced through PD (Duncan, Pilitsis & Piegaro 2010). In abstract subjects like science, the use of instructional materials, especially e-learning tools (such as e-textbooks and online reading materials, simulated laboratories, online course platforms, interactive whiteboards, and online assessment question banks) are vital (Bada & Jita 2021). These materials facilitate understanding and reduce the need for repeated explanations, easing the burden on teachers and students (Zhang Zhansheng 2022). A positive attitude in teachers, characterized by enthusiasm and a growth mindset, significantly enhances teaching effectiveness and student motivation (Mensah 2013). Proactive teachers can better handle challenges, adapt to new methods, and inspire students, creating a dynamic classroom environment (Bolhuis & M Voeten 2004).

Lesson planning, self-efficacy, management skills, and working hard each account for 3% of the total strategies, highlighting their critical role as essential teacher skills. Lesson planning has proven to be a valuable tool for understanding and uncovering teachers' pedagogical content knowledge (PCK) of model-based scientific inquiry (Macalalag 2012). Through lesson planning, teachers consider students' background knowledge, skills, and experiences to effectively teach the key ideas of their lessons (Minken et al. 2021). it also serves as important artifacts of teaching (Minken et al. 2021). Teachers with high self-efficacy are more likely to exhibit effective classroom management (Woolfolk, Rosoff & Hoy 1990), utilize innovative teaching methods (Ghaith & Yaghi 1997), set higher learning goals for their students (Ross & Bruce 2007). Additionally, strong classroom management skills are essential for creating a conducive learning environment, thereby enhancing effective teaching and learning (Nkhata et al. 2020). Hard work is fundamental to teaching, as it drives teachers to continuously improve their practices and stay committed to their students' success. Together, these strategies form a robust framework that supports teacher effectiveness and student success (Engström & Norström 2022).

In addition to the aforementioned strategies, support from family and school (Sun & Liu 2022), participation in lesson competitions (Sun & Liu 2022), game-based learning (Kurupınar, Yüksel & Kurt 2022), synthesizing teaching methods, innovative learning (Musa 2020), and training program (Al-Shehria & Gharamah 2021; Valdmann, Holbrook & Rannikmäe 2020) are also mentioned in teachers' PD strategies. These six strategies each account for 2% of the total strategies mentioned.

The effective implementation of these strategies can significantly enhance teachers' professional competencies and teaching effectiveness, further promoting the improvement of educational quality. Successful implementation of these strategies requires support and resources from schools and the education system, as well as the teachers' own efforts,

creating a virtuous cycle that fosters continuous PD for teachers and comprehensive growth for students.

Conclusion

This article provides a systematic analysis and synthesis of PD strategies for science teachers, highlighting key areas for future research and practice to support continuous professional growth for teachers and comprehensive development for students. Despite extensive research on teachers' PD strategies, specific focus on science teachers is limited (Metlí & Akıs 2022). From 2020 to 2025, out of over 10,000 articles, only 38 addressed science teacher PD. This period saw a growth in research, peaking before a decline in 2023.

Reviewing these 38 articles, 17 distinct PD strategies were identified. Key strategies included collaboration, assessment and evaluation, pedagogy, content, and technology, underscoring their critical role in science teacher PD. Despite the broad range of strategies identified, the PD of teachers is dynamic and varies from person to person (Zhu Min 2019). Therefore, when designing PD strategies for teachers, the specific challenges faced and needs of science teachers require further exploration to develop targeted support mechanisms that can enhance their teaching effectiveness and professional satisfaction (Kabilan & Veratharaju, 2013 & Jiang et al., 2020).

Recommendation

Korthagen (2017) argues that teachers' thoughts, feelings, wishes, ideas, potentials, inspirations, and goals play motivating roles in the PD process. Therefore, as a prerequisite for teachers' PD, it is essential to understand the genuine needs of teachers for professional growth (Yenen & Yöntem 2020)

In the 21st century, technology increasingly intertwines with daily life, making the integration of teaching and technology a crucial area for research (Bumagat et al. 2023). Future studies should focus on how technological advancements can enrich teachers' skills and enhance classroom effectiveness. By incorporating tools such as virtual reality (VR), augmented reality (AR), and other emerging technologies (such as e-textbooks, online reading materials, simulated laboratories, animations, applets, online course platforms, interactive whiteboards, and online assessment question banks), teachers can create immersive and engaging learning environments that make abstract scientific concepts more tangible and understandable (Akram et al. 2022). These tools can improve classroom dynamics, increase student interest, and enhance learning outcomes in science (Sunzuma 2023). Additionally, research should explore the development of PD programs that enhance teachers' technological skills.

Developing PD strategies that integrate technology can significantly improve teaching practices and student engagement (Akram et al. 2022; Baharom et al. 2020). By understanding and addressing the specific needs and challenges of science teachers, and by fostering continuous innovation in teaching through technology, educators can better prepare students for a future shaped by scientific and technological advancements.

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