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A Systematic Literature Review of Inquiry-Based Teacher Professional Development Programs: Types and Impacts on Teachers and Students (2013-2023)

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Abstract

This study aims to conduct a literature analysis of Inquiry-Based Teacher Professional Development Programs (I-BTPDP), focusing on the types of programs and their impact on both teachers and students. The research employs a systematic literature review (SLR) consisting of four main stages: identification, screening, eligibility, and inclusion. The initial identification and screening process is based on the following criteria: 1) articles published between 2013-2023, 2) content related to inquiry-based science teacher professional development programs, 3) articles written in English and peer-reviewed, and 4) content discussing the impact of inquiry-based science teacher professional development on teachers and/or students. After the screening process, 34 eligible articles were selected for analysis. Data analysis was conducted through coding based on the types of I-BTPDP and their impact. The literature review results show that the types of I-BTPDP include programs directly focused on inquiry-based learning, programs with a focus on the Nature of Science (NoS), technology-based programs, and partnership-based programs. Furthermore, the impact of I-BTPDP on teachers includes hands-on experience with the scientific inquiry process, enhanced understanding of planning and implementing inquiry-based learning, and increased confidence and interest in conducting inquiry-based learning. As for students, the impact of I-BTPDP includes improvements in content knowledge, attitudes towards science, and engagement in the inquiry process

Keywords: inquiry-based teaching, professional development program, science learning

Introduction

Inquiry-based science learning has long been recommended as an approach that can help improve the quality of science education (Seneviratne et al., 2019). Over the past few decades, inquiry-based learning has gained increasing attention in science education research (Glackin & Harrison, 2018; Houseal et al., 2014; Martins-Loução et al., 2020; van Uum et al., 2021). Furthermore, in-

quiry-based science learning has been promoted worldwide as part of efforts to achieve scientific literacy among the public (Ladachart et al., 2022), increase students' curiosity, and provide a more authentic science learning experience (Glackin & Harrison, 2018). In a more specific context, inquiry-based learning aims to develop an understanding of scientific practices and the nature of science (Capps & Crawford, 2013; Kali et al., 2018).

However, inquiry-based learning still faces various challenges, particularly in its implementation in schools. The most common challenges relate to teachers' knowledge and understanding of inquiry-based learning. Research shows that science teachers in secondary schools still experience difficulties in understanding and implementing the scientific method and inquiry-based learning (Herranen et al., 2019; Kurtén & Henriksson, 2021). Another challenge faced by science teachers is the limited ability to integrate science content and practices actively involving students in scientific investigation and the application of science in real life (Banilower, 2019; Lotter et al., 2020).

These challenges in implementing inquiry-based science learning are being addressed in various ways, such as continuous professional development for teachers. Science teachers should be involved in professional development programs to improve the quality of the learning process they conduct with students (Martins-Loução et al., 2020). Furthermore, it is stated that science teachers should participate in professional development programs related to inquiry to strengthen pedagogical strategies and scientific content in reformative learning environments (Cigdemoglu & Köseoğlu, 2019). Research indicates that teachers participating in professional development programs related to inquiry experience changes in classroom teaching practices (Yang et al., 2022). Thus, inquiry-based professional development programs for teachers are essential and should be continuously implemented to deliver meaningful and quality science learning.

Inquiry-based teacher professional development programs continue to evolve and attract the attention of science education researchers. These programs are provided to science teachers and preservice teachers using various methods, different timeframes, targeted teachers, and developmental focuses. Differences in methods and duration of teacher professional development have varying impacts on the quality of training outcomes, such as encouraging teachers to engage in continuous learning and apply their training in the classroom context (Kurtén & Henriksson, 2021). However, some research findings indicate that there is not always a correlation between the duration of training and the quality of results (Shaun Murphy et al., 2020), nor with the sustainability of teachers' ability to apply the training outcomes in the classroom (Lotter et al., 2020; van Uum et al., 2021).

Additionally, teachers face various obstacles in inquiry-based professional development, such as limited resources, time, and technical support (Viera et al., 2021; Mckeown et al., 2016). Moreover, the training available does not always cater to teachers' specific needs for implementing inquiry in the classroom. This makes it difficult for teachers to adapt inquiry methods to the classroom learning context. The training provided often lacks in-depth and continuous facilitation of inquiry-based learning, making it challenging for teachers to develop the competencies to address practical challenges in the learning process (Baan et al., 2021).

Over time, various training efforts directed at enhancing teachers' professional development in inquiry-based learning have continued to receive attention from various stakeholders. These programs, known as Inquiry-Based Teacher Professional Development Programs (I-BTPDP), are developed to support teacher professionalism through different approaches, considering the goals, targets, and emphasis in inquiry training. Some training focuses on improving basic skills in designing and implementing inquiry-based learning (Hofer & Lembens, 2019; Mckeown et al., 2016). Meanwhile, other professional development programs emphasize a deeper understanding of inquiry principles and their application across various curriculum contexts (Chang et al., 2016; Parker et al.,

2016). These differences reflect the varying needs of teachers, according to their backgrounds, experiences, and challenges faced in classroom teaching.

The variety of inquiry-based teacher professional development programs indicates that training for teachers has different needs and challenges. Therefore, there is a need for a systematic literature review on the types and impacts of various inquiry-based teacher professional development programs. Such a review could help identify the most supportive approaches for enhancing teachers' competencies in addressing the challenges of inquiry-based learning in the field. Additionally, a comparative review can provide insights into the mapping of key elements in the programs, such as technical support, resource availability, and training sustainability. With a systematic review, inquiry-based teacher professional development can be designed to meet needs and challenges. In this article, the systematic literature review focuses on answering the following research questions:

1. What are the types of Inquiry-Based Teacher Professional Development Programs that enhance teacher professionalism in inquiry-based learning?
2. What is the impact of Inquiry-Based Teacher Professional Development Programs on the quality of teachers and student learning outcomes?

Materials and methods

Research Design

This study uses a Systematic Literature Review (SLR) approach to identify, analyze, and synthesize existing research on inquiry-based teacher professional development (PD) programs. The systematic literature review in this study consists of four main stages: identification, screening, eligibility, and inclusion (Moher et al., 2009; Zhang & Bae, 2020). The SLR framework enables a comprehensive and structured examination of the literature, ensuring that the research findings are valid and reliable.

Search Strategy

The database search for reviewed articles used keywords such as "Teacher AND Program AND Development," "Inquiry-Based Teaching," and "TPD in Inquiry." These keywords were chosen for their relevance to the main topic, which focuses on inquiry-based teacher professional development programs. The article search was conducted using tools like Publish or Perish and Scopus.com. The database search was restricted to articles published between 2013 and 2023. Additionally, the search was limited to full-text articles in English. Furthermore, clarity and relevance to the specified keywords were integral to the database search strategy. The systematic literature review in this study follows four main stages: identification, screening, eligibility, and inclusion.

Based on Figure 1, the initial database search yielded 267 articles. After the preliminary selection process to remove duplicate articles, 213 articles remained. The subsequent screening process applied predetermined inclusion criteria, and through an analysis of titles and abstracts, 68 articles were identified. These were then further screened for the availability of full text. After analyzing titles and abstracts to assess their relevance to the study focus—such as teacher professional development programs, inquiry-based teaching, and TPD in inquiry—a final database of 34 articles was identified.

Inclusion and Exclusion Criteria

The initial identification and screening process was based on the following inclusion criteria: 1) Articles published between 2013 and 2023, ensuring the study is current within the science education research community. 2) Content addressing inquiry-based science teacher professional development programs. 3) Articles published in English and subject to peer review. 4) Content discussing the impact of inquiry-based science teacher professional development on teachers, students, or oth-

ers. The exclusion criteria included: 1) Articles discussing inquiry-based learning without linking it to teacher professional development. 2) Studies focused on students or teachers outside the formal education context. 3) Articles that are reports, editorial reviews, or not empirical research. 4) Literature that is not accessible in full-text form. These criteria were selected to ensure the literature aligns with the research questions.

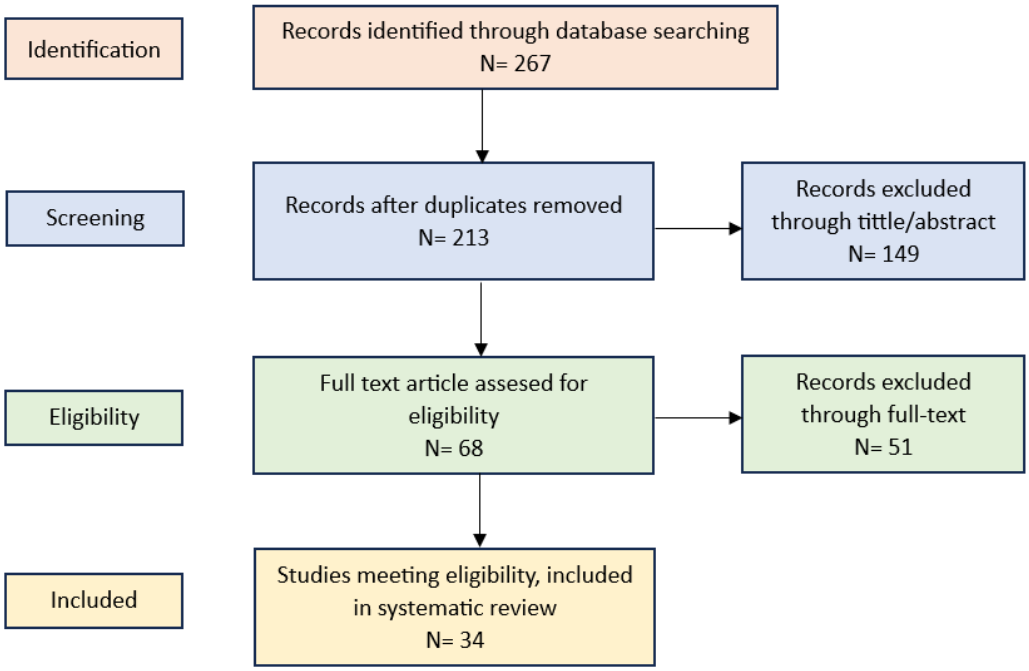

Figure 1. SLR Stages (Moher et al., 2009)

Data Analysis

The final identified database was analyzed and synthesized by creating a literature matrix containing the author names, publication year, journal name, the specific Inquiry-Based Teacher Professional Development Program (I-BTPDP) name, I-BTPDP type, I-BTPDP participants, I-BTPDP duration, and the impact of I-BTPDP implementation. To facilitate the analysis of each study across these 34 articles, coding was conducted based on different I-BTPDP types, target participants, and impacts. Coding for I-BTPDP types helps in comparing the effectiveness of various I-BTPDP types. Additionally, coding for I-BTPDP target participants aids in mapping the effectiveness of targeted I-BTPDP implementation, while coding for I-BTPDP impacts helps in determining the benefits of the I-BTPDP programs..

Results

Statistical Data on Inquiry-Based Teacher Professional Development Programs (I-BTPDP)

This section presents statistical data regarding the professional development of teachers in inquiry-based programs. The data includes the duration of the training programs, the number of participants, the status of teachers involved, and the level of education they teach. The analysis of 34 articles provides the following data on program duration:

Table 1. Duration of Inquiry-Based Teacher Professional Development Programs (I-BTPDP)

Program Duration	Number of Programs
<3 months	9
$3 \leq x \leq 6$ months	7
$6 < x \leq 12$ months	7
$1 \leq x \leq 2$ years	7
>2 years	4

Table 1 shows that the duration of Inquiry-Based Teacher Professional Development Programs (I-BTPDP) generally varies depending on the needs of each program. The shortest duration is less than 3 months, encompassing 9 programs, while other programs typically last from more than 3 months to 2 years. Research findings indicate that the duration of I-BTPDP has different effects on the outcomes of the training. A longer I-BTPDP duration does not necessarily yield better results than shorter programs. Indeed, some shorter-duration programs have had a significant impact on teachers and students, sometimes even more so than longer programs. Thus, duration alone is not the key factor in creating impactful programs for participants.

Longer-duration I-BTPDPs are often implemented when introducing a new inquiry-related curriculum, requiring multiple phases in the training process. This aligns with research showing that long-duration I-BTPDPs designed to introduce a new curriculum in a gradual manner significantly improve teacher competencies (Maass & Engeln, 2018). Additionally, long-duration I-BTPDPs are also used in programs that track the development of teachers' self-efficacy in inquiry-based learning over time, allowing for an accurate assessment of the impact of I-BTPDP on teachers' self-efficacy and inquiry skills (Murphy et al., 2015; Lotter et al., 2018). Meanwhile, shorter-duration I-BTPDPs are aimed at providing teachers or prospective teachers with an introduction to and experience in inquiry-based teaching (Capps & Crawford, 2013; Glackin & Harrison, 2018). Other studies suggest that shorter I-BTPDPs focus on developing inquiry skills within specific areas only (Sağlam & Şahin, 2017).

In another aspect, if viewed from the number of participants involved in the Inquiry-Based Teacher Professional Development Programs, the following statistical data is obtained:

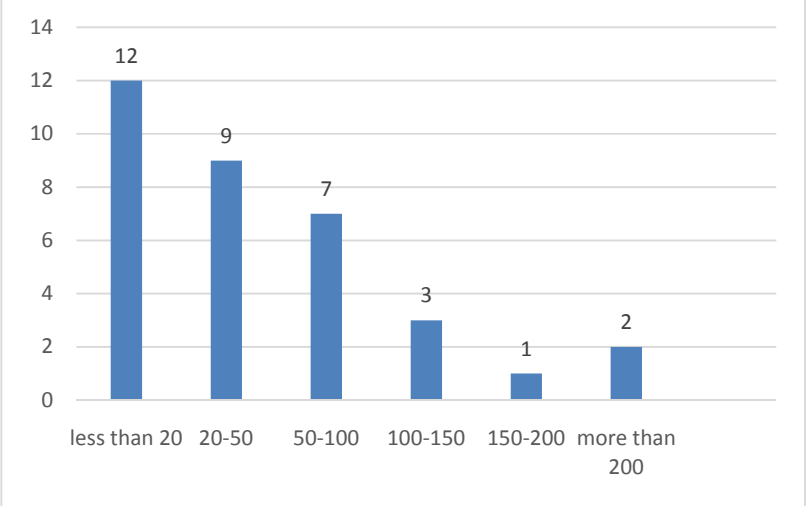

Figure 2. Number of Participants in I-BTPDP

In Figure 2, 12 Inquiry-Based Teacher Professional Development programs involved fewer than 20 participants. This indicates that many Inquiry-Based Teacher Professional Development activities are conducted with a limited number of participants, which allows for a more focused and impactful experience for those involved. Additionally, 9 Inquiry-Based Teacher Professional Development programs were organized with between 20-50 participants, while a few others involved more than 100 participants.

Studies in some research indicate that there is no explicit evidence showing that the number of participants in I-BTPDP significantly affects the training process and outcomes. However, several studies suggest that programs with fewer participants tend to foster more interactive and productive engagement, resulting in a meaningful impact on participants (Amolins et al., 2015; Pavez et al., 2016; Wilkerson et al., 2016).

Teacher Status and Educational Levels

In addition to program duration and participant numbers, this article also provides a statistical mapping of the participants' status and the school levels where they teach. The results of this mapping are presented in Figure 3. This mapping helps to identify the professional backgrounds of participants, whether they are pre-service or in-service teachers, and the educational levels at which they work (e.g., primary, secondary, or high school). By examining these characteristics, the study can better understand how different backgrounds and teaching contexts may influence the effectiveness and impact of Inquiry-Based Teacher Professional Development programs.

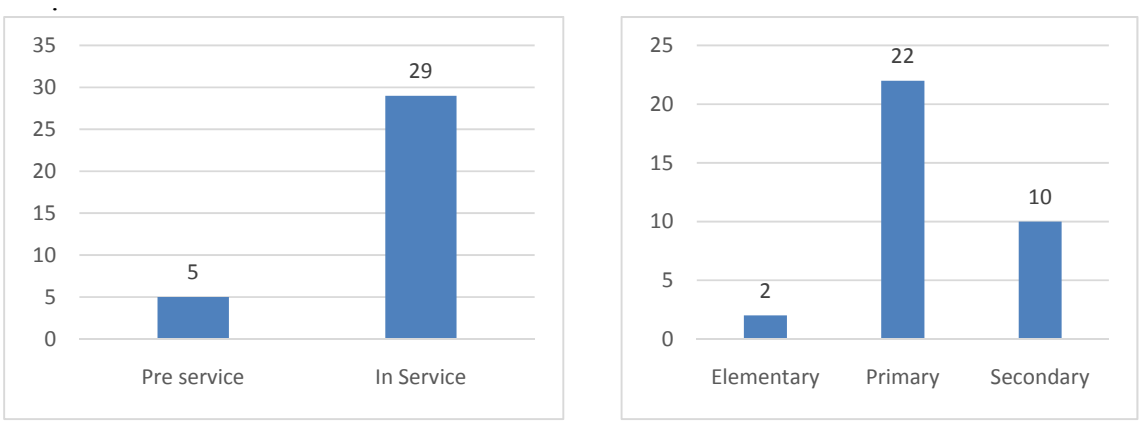

Figure 3. Teacher Status and Educational Levels

Figure 3 shows that participants in Inquiry-Based Teacher Professional Development Programs (I-BTPDP) are generally in-service teachers with varying levels of teaching experience. A smaller number of these programs involve pre-service teachers. For in-service teachers, I-BTPDPs serve as a form of continuous professional development aimed at enhancing their professionalism and enabling them to deliver more meaningful and impactful science instruction for students (Kurten & Henrikson, 2021). In-service programs focus on addressing issues encountered in the classroom, allowing participants to directly implement program outcomes within their school settings (Kartal et al., 2018). Thus, I-BTPDPs benefit in-service teachers by improving teaching quality, learning processes, and student outcomes.

For pre-service teachers, I-BTPDPs aim to prepare future science teachers to deliver inquiry-based science instruction (Mor et al., 2013). Since pre-service teachers generally lack comprehensive field experience, I-BTPDPs emphasize preparing these future teachers to face various chal-

lenges in schools (Wilkerson et al., 2018). The program also emphasizes best practices in conducting inquiry-based science instruction to enhance the learning experience for both teachers and students.

Additionally, this study categorizes participants based on the education level at which they teach science. In general, both in-service and pre-service teachers involved in I-BTPDPs teach at the primary level as science instructors. A smaller portion of participants are elementary and secondary school teachers.

Discussion

Types of Inquiry-Based Teacher Professional Development Programs (I-BTPDP)

The analysis of 34 database articles reviewed through a systematic literature review identified different types of Inquiry-Based Teacher Professional Development Programs (I-BTPDP). Here is an explanation of the programs in each category:

Programs Focused on Inquiry-Based Learning (IBL)

This teacher professional development program focuses on inquiry-based learning, training teachers to design science instruction that incorporates inquiry by directly involving them in scientific investigation across various teaching contexts and situations. A review of research literature highlights several types of training programs. One such program is Continued Professional Development with a focus on Inquiry-Based Learning (IBL), aimed at equipping elementary science teachers to implement inquiry-based science instruction consistently (Kurtén & Henriksson, 2021). This program consists of four sessions involving 26 science teachers, who receive training on inquiry-based learning to be applied in their respective schools.

Another professional development program focused on preparing teachers for inquiry-based science instruction is Cognitive Apprenticeship-Based Professional Development (Peters-Burton et al., 2015). Conducted over one year, this program involves teachers in authentic experiences of scientific practice and research, guided by a scientist or science researcher. This program aims to change teachers' perceptions of scientific practice and research, thereby influencing their views on implementing inquiry-based learning in their classrooms.

A different program designed to prepare teachers for inquiry-based learning involves using natural environments, such as botanical gardens (Glackin & Harrison, 2018). In this program, eight science teachers visit the Royal Botanical Gardens with a university tutor. Teachers are introduced to inquiry-based learning using the botanical garden and the challenges of conducting inquiry-based instruction in natural settings. This program emphasizes inquiry-based learning that engages scientific investigation directly within the environment, using the surrounding area as a natural laboratory to develop students' scientific inquiry skills. A similar program utilizes botanical gardens as a context for inquiry-based science instruction, emphasizing continuous teacher development through formal and informal contexts for scientific investigation as a unique component of inquiry-based learning (Martins-Loução et al., 2020). In the botanical garden context, teachers are introduced to inquiry-based learning on topics such as biodiversity and climate change.

This professional development program, which directly focuses on inquiry-based learning, faces several challenges, especially after the training ends. These challenges include low teacher confidence in implementing the training results in their own classrooms (Kurtén & Henrikson, 2021). Another challenge teachers encounter after inquiry-based learning training is that many tend to revert to traditional practices after a few months back at school (Peters-Burton et al., 2015). Although there are some challenges associated with inquiry-focused I-BTPDP, the training programs have the potential to be implemented for teachers from elementary to high school levels. Moreover,

inquiry-focused training programs utilizing botanical gardens can serve as an alternative for teacher professional development beyond the confines of the classroom.

Programs Focused on the Nature of Science (NOS)

The Nature of Science (NOS) is an essential component of science education, aiming to provide an authentic, simplified, and broadly society-oriented portrayal of science (Koponen, 2021). NOS and inquiry are key elements in science education, with the goal of helping students develop an understanding of NOS and inquiry as essential components of scientific literacy (Takda et al., 2022). Therefore, to enhance teachers' understanding of inquiry-based learning, training focused on NOS serves as a professional development program for science education.

The Nature of Science-Continuing Professional Development Program (NOS-CPD) is a sustained science teacher professional development program that emphasizes shifting science teachers' views on NOS (Erdas Kartal et al., 2018). This program is designed in a collaborative and reflective environment, integrating NOS principles into the school curriculum. This training program better prepares teachers for inquiry-based learning, emphasizing the scientific method, creativity, and imagination in science. Consequently, teachers' views on NOS become more open to inquiry-based learning.

Another professional development program that emphasizes understanding NOS is the training program that combines the Nature of Science and the History of Science (NoS-HoS CPD) (Pavez et al., 2016). This training program focuses on developing teachers' understanding of the nature and history of science. Understanding NoS and HoS plays an important role in designing effective science instruction to facilitate inquiry processes and enhance students' scientific literacy in schools. Another related program, the NoS-Systematic Research-Based Professional Development, is systematically designed to improve teachers' and students' understanding of the nature of scientific knowledge and scientific inquiry (Lederman & Lederman, 2019). This program helps teachers strengthen their pedagogical knowledge in planning and implementing NOS-based instruction in an explicit and reflective way.

NOS-oriented I-BTPDP has the potential to be implemented in training programs aimed at deeply developing teachers' scientific abilities and reinforcing scientific concepts. In NOS-based training, teachers engage in various practices to understand the nature of science, including its products, processes, and scientific attitudes. NOS-based training programs can facilitate deep mastery of scientific concepts and skills (Faikhamta, 2013). However, NOS-based training presents several challenges for teachers, including low scientific attitudes among participants, which can prolong NOS development. Furthermore, weak understanding of NOS can hinder the training process.

Programs Focused on Integrating Technology in Science Learning

The integration of technology has evolved as a pedagogical tool that transforms inquiry-based learning into a more active and innovative inquiry learning environment (Premthaisong & Srisawasdi, 2024). To produce technology-integrated inquiry-based learning, science teachers need skills in lesson design. Therefore, training programs focused on designing inquiry-based learning with a focus on technology integration are essential. One such program is the Blended Professional Development Program. This program aims to assist science teachers in solving authentic scientific problems with active student involvement (Belland et al., 2015). The program includes offline seminar and workshop activities lasting 9.5 class hours, as well as 4 hours of online activities. This program prepares science teachers to design inquiry-based learning with a scaffolding approach to problem-solving.

Another training program that integrates technology is the Immersive Virtual Environment Professional Development Program (IVE-PDP). This training program emphasizes preparing sci-

ence teachers to design inquiry-based science instruction by applying authentic scientific methods with the help of technology (Mills et al., 2019). This program impacts teachers' confidence in implementing inquiry-based learning, although they still face limitations in classroom execution. Furthermore, another inquiry-based training program with a focus on technology integration is the Project-Based Professional Development Program with Ultrasound Scanning. This program is collaboratively conducted between the medical faculty and the education faculty, lasting 115 hours and involving 20 science teachers. During its implementation, this program trains teachers to conduct scientific inquiries on authentic problems using ultrasound scanning (Lotter et al., 2020). After completing this training program, teachers are asked to apply their training outcomes by designing inquiry-based learning for their science classes. Additionally, teachers are also required to develop problem-based science curricula with an inquiry approach in their lesson planning for other science subjects.

Another technology-integrated training program is the Modeling-Focused Professional Development Workshop. This program offers collaborative and participatory training for teachers through computational modeling and animation on various science topics (Wilkerson et al., 2016). In the training sessions, teachers work in groups to build diffusion models using animation systems and computational simulations, and design lesson plans to utilize these tools. Content analysis from group discussions and lesson plans is used to document attention to content, representation, revision, and evaluation during the workshop.

The I-BTPDP program utilizing technology is becoming increasingly relevant as the use of technology in education becomes more widespread. Training that incorporates technology can serve as an alternative to inquiry-based training, especially for teachers who are already accustomed to using technology. Inquiry development training leveraging technology can also provide technology-based inquiry learning experiences, such as using virtual laboratories and other media types (Buckner & Kim, 2014). However, there are some obstacles to technology-based inquiry learning training, such as insufficient availability of technological tools, which can lead to discrepancies between the training environment and actual classroom conditions. Another barrier in technology-assisted inquiry training is teachers' low proficiency in using technological tools, which can make the training process less effective.

Programs Focused on Partnerships

Partnership programs in the professional development of science teachers play a crucial role in enhancing participation from all parties and emphasizing the importance of theoretical and practical knowledge in inquiry-based learning (Juuti et al., 2021). These partnership programs involve various stakeholders, such as scientists, the community, and practitioners, as part of the ongoing professional development process. One such professional development program involving partnerships is the Student-Teacher-Scientist Partnerships (STSPs), which engages scientists, teachers, and students in the development of inquiry-based science education. This training program has great potential to enhance content knowledge in science, attitudes towards science, and pedagogical practices for both students and teachers. It provides authentic experiences that deepen scientific understanding and foster a positive attitude toward science (Houseal et al., 2014).

Another partnership-focused training program is the Research Experience for Teachers (RET), which offers science teachers the opportunity to collaborate with scientists to engage directly in authentic inquiry processes (Saka, 2013). This training program provides teachers with authentic experiences to deeply understand scientific processes. Furthermore, this program emphasizes the application of inquiry in more engaging pedagogical practices, challenging teachers to implement inquiry-based learning in their classrooms. Overall, partnership-focused training programs offer sci-

ence teachers experiences from diverse perspectives, such as those of scientists and the community. Thus, partnership training programs direct attention to the relevance between theoretical knowledge and practical knowledge.

Training programs that involve external partners enrich the content by presenting diverse and varied perspectives. The involvement of scientists, the community, and other relevant stakeholders in inquiry learning provides different experiences for teachers participating in the training (Attard et al., 2021). However, partnership-based training faces challenges, such as difficulties in finding and identifying partners willing to share knowledge and experience with teachers. Moreover, partners involved in the training sometimes do not fully understand the needs of teachers, which can lead to training not proceeding as planned (Hennessy et al., 2021).

The Impact of Inquiry-Based Teacher Professional Development Programs (I-BTPDP)

Inquiry-Based Teacher Professional Development Programs (I-BTPDP) aim to enhance science teachers' professionalism in conducting science teaching in classrooms. Each program, however, has specific goals and impacts tailored to the needs of the teachers. This section discusses the impact of inquiry-based professional development programs on both teachers and students.

Impact of Inquiry-Based Professional Development Programs on Teachers

Inquiry-Based Teacher Professional Development Programs (I-BTPDP) have a positive impact on science teachers across various educational levels, including elementary, primary, and secondary schools. The Continuous Professional Development (CPD) program focusing on inquiry assists teachers in developing more interactive and participatory teaching methods, despite facing challenges such as limited time (Kurtén & Henriksson, 2021). Furthermore, this program aids teachers in planning and implementing inquiry-based learning projects in their classrooms. Through continuous training, teachers can design inquiry-based learning systematically, from lesson planning to meaningful execution of inquiry-based instruction. Additionally, ongoing professional development enhances teachers' understanding of scientific concepts.

Another CPD program focusing on the Nature of Science (NOS) positively impacts teachers by enhancing their understanding of scientific methods, the nature of science, creativity and imagination in science, and the social and cultural influences on science (Erdas Kartal et al., 2018). This CPD-NOS program broadens teachers' perspectives on planning and implementing inquiry-based science education. It emphasizes the importance of formative assessment and ongoing analysis of the learning process to ensure that inquiry-based learning is of high quality. Consequently, teachers become more skilled in conducting formative assessments that focus on the process during instruction. This approach encourages teachers to move beyond solely relying on summative assessments and fosters a deeper understanding of assessment strategies and continuous feedback.

The Student Teacher Scientist Partnerships (STSPs) program impacts teachers in several areas, such as significantly increasing content knowledge in science, fostering positive attitudes toward science, and facilitating authentic science teaching practices that involve scientific inquiry (Houseal et al., 2014). The Research Experience for Teachers program, which emphasizes authentic experiences for teachers, also positively affects science educators. Through positive collaboration with scientists, teachers gain a deeper understanding of scientific processes and procedures, which enhances their interest in implementing inquiry-based science education (Saka, 2013).

Various training programs that integrate technology positively influence science teachers. The Modeling-Focused Professional Development Workshop provides teachers with direct involvement in diverse aspects of scientific modeling through computational simulations and animations (Wilkerson et al., 2016; Fatma et al, 2024). This training has a significant impact on teachers' richer understanding of scientific modeling when engaged in simulations compared to animations. It

also underscores the importance of technology in scientific modeling within the inquiry-based learning process, ultimately developing teachers' skills in utilizing technology as a teaching tool.

Another technology-based training program, the Immersive Virtual Environment Professional Development (IVE-PD), changes teachers' beliefs about the importance of inquiry-based learning as a meaningful part of their teaching practice (Mills et al., 2019). Meanwhile, the Project-Based Professional Development Program with Ultrasound Scanning enhances teachers' content knowledge and the quality of inquiry-based instruction during the program, enabling them to modify the learning process to better meet students' needs (Lotter et al., 2020). Moreover, technology integration in the Blended Professional Development Program positively impacts teachers by employing scaffolding techniques in problem-based and inquiry-based learning, such as providing feedback and posing questions that encourage critical thinking (Belland et al., 2015). The ability to ask questions is crucial in the inquiry learning process; thus, such training equips teachers with the skills to ask more effective and appropriate questions in inquiry-based teaching.

Impact of Inquiry-Based Professional Development Programs on Students

Inquiry-Based Teacher Professional Development Programs (I-BTPDP) significantly impact teachers in planning and implementing inquiry-based learning in their classrooms. The inquiry-based instruction delivered by teachers directly influences the quality of learning experienced by students. Consequently, I-BTPDP programs indirectly benefit students as well. Several studies have indicated that these programs lead to positive outcomes for students, including enhanced understanding of the scientific investigation design process through continuous iteration (Mor & Mogilevsky, 2013). Additionally, students exhibit increased content knowledge and a more positive attitude towards science and scientists (Houseal et al., 2014). Such impacts can have long-term effects on students, fostering their interest in science-related careers and enhancing their adaptive skills in addressing everyday challenges.

In a broader context, I-BTPDP programs enhance students' self-efficacy and engagement in inquiry-based learning (Seneviratne et al., 2019). Self-efficacy is crucial for students' success in learning and their ability to confront future challenges. Therefore, the training that teachers receive to deliver meaningful inquiry-based instruction equips students with the readiness to face real-world challenges.

Other training programs also enable students to deepen their understanding of the Nature of Science (NoS) and scientific inquiry, helping them grasp scientific content and processes while fostering a positive attitude towards science (Lederman & Lederman, 2019). A profound understanding of NoS allows students to appreciate natural phenomena better and aids in making informed decisions related to scientific phenomena in daily life. These findings demonstrate that students benefit from I-BTPDP, both in the short and long term. Short-term impacts include increased interest and motivation to learn scientific content, while long-term benefits involve developing students' scientific thinking skills in understanding phenomena and scientific concepts. This meaningful understanding equips students for real-life situations and future challenges. Based on this evidence, it is essential to implement I-BTPDP programs continuously to maintain the professionalism of teachers and the quality of classroom instruction. This approach will ensure sustained positive impacts on students over time.

Conclusion

Inquiry-Based Teacher Professional Development Programs (I-BTPDP) are an essential part of science education to maintain the quality and professionalism of science teachers when teaching in the classroom. The results of a systematic literature review (SLR) of 34 articles focused on the

types and impacts of I-BTPDP show that these programs consist of various types with different developmental focuses, including programs that directly emphasize inquiry-based learning, programs focused on the Nature of Science (NoS), technology-based programs, and partnership-based programs. Furthermore, the impact of I-BTPDP on teachers includes providing direct experience in the scientific inquiry process, enhancing understanding of the planning and implementation of inquiry-based learning, and increasing confidence and interest in conducting inquiry-based teaching. Meanwhile, the impact of I-BTPDP on students includes improved content knowledge, attitudes toward science, and greater engagement in the inquiry process.

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