Routledge
Taylor & Francis Group

Studies in Science Education

ISSN: 0305-7267 (Print) 1940-8412 (Online) Journal homepage: www.tandfonline.com/journals/rsse20

Inquiry-based science education in science teacher education: a systematic review

Tonje Tomine Seland Strat, Ellen Karoline Henriksen & Kirsti Marie Jegstad

To cite this article: Tonje Tomine Seland Strat, Ellen Karoline Henriksen & Kirsti Marie Jegstad (2024) Inquiry-based science education in science teacher education: a systematic review, Studies in Science Education, 60:2, 191-249, DOI: 10.1080/03057267.2023.2207148

To link to this article: https://doi.org/10.1080/03057267.2023.2207148

STUDIES IN SCIENCE EDUCATION
2024, VOL. 60, NO. 2, 191–249
https://doi.org/10.1080/03057267.2023.2207148

Routledge
Taylor & Francis Group

OPEN ACCESS Check for updates

Inquiry-based science education in science teacher education: a systematic review

Tonje Tomine Seland Strat[a], Ellen Karoline Henriksen[a,b] and Kirsti Marie Jegstad[a]

[a]Department of Primary and Secondary Teacher Education, OsloMet – Oslo Metropolitan University, Oslo, Norway; [b]Department of Physics, University of Oslo, Oslo, Norway

ABSTRACT

Inquiry is central in science education and therefore also in pre-service teacher (PST) education. In this systematic review of 142 empirical articles, we examine research on inquiry-based science education (IBSE) in teacher education between 2000 and 2022. The aim is to investigate how and with what outcomes IBSE is used in PST education. The included articles were categorised according to whether the PSTs worked with inquiry in the role of learner or in the role of teacher and also according to the cognitive domains of inquiry (epistemic, procedural, conceptual, social, pedagogical, or affective). The review shows that IBSE is used for PSTs to learn science concepts and processes and how to teach science through inquiry; however, few studies highlight the transition between these. In terms of cognitive domains, the procedural, conceptual, pedagogical, and affective domains dominated, whereas fewer articles addressed the epistemic or social domains. Favourable outcomes of IBSE for science understanding, teaching competence and improved attitudes or self-efficacy were reported. Challenges were noted, for example with implementing IBSE in school placement after having learned about it in campus-based courses. Finally, we offer recommendations for fruitful ways of implementing IBSE in PST education and suggest areas for future research.

KEYWORDS

Inquiry-based science education; science teacher education; pre-service teachers; cognitive domains; systematic review

Introduction

Inquiry-based science education (IBSE) is promoted in official policy and curriculum documents and in the science education research literature (Crawford, 2014; European Commission Directorate-General for Research Innovation, 2015; Furtak et al., 2012; Gericke et al., 2022; National Research Council, 1996, 2000; Rocard et al., 2007; Rönnebeck et al., 2016). In recent years, the expression 'scientific practices' has become prevalent and is often used synonymously with IBSE (Crawford, 2014; Cruz-Guzmán et al., 2020; National Research Council, 2012; Rönnebeck et al., 2016). In this article, we have chosen to use the term IBSE, which is defined by Crawford (2014) as a process that

> involves engaging students in using critical thinking skills, which includes asking questions, designing and carrying out investigations, interpreting data as evidence, creating arguments,

CONTACT Tonje Tomine Seland Strat tonjeto@oslomet.no

> building models, and communicating findings in the pursuit of deepening [one's] understanding by using logic and evidence about the natural world (Crawford, 2014, p. 515).

This definition includes central scientific practices and refers to a learning process in which learners are actively engaged to understand scientific concepts and processes, as well as the nature of science (NOS). This definition also encompasses skills that are highlighted in 'Program for International Student Assessment (PISA) 2024, such as creativity, innovation, problem solving and critical thinking (OECD, 2020).

IBSE is rooted in the work of Dewey (1938), who founded inquiry in experience: doing and then reflecting on what happened. According to Dewey (1938), learning experiences should be collaborative and placed in a frame of active learning. IBSE returned to prominence in the 1990s through the National Science Education Standards in the United States (National Research Council, 1996). Today, it is a recommended approach to teaching science in school because it can provide pupils with key knowledge and skills and contribute to motivation (Aditomo & Klieme, 2020; Adler et al., 2018; Crawford, 2014).

Teacher educators act as 'the teachers of the teachers' (Kelchtermans et al., 2018) and their role in fostering IBSE in the teaching profession is important. During teacher education, PSTs should gain experience in IBSE as learners through authentic science experiences and should be scaffolded in how to put it into practice with their future pupils (Crawford & Capps, 2018; Sjøberg, 2019). Therefore, it is of interest how IBSE can best be implemented in teacher education to prepare PSTs for their professional practice as science teachers. To the best of our knowledge, no other systematic reviews on IBSE in science teacher education have been published. In a review conducted by Rönnebeck et al. (2016) on research on inquiry in school science, it was suggested that a corresponding review of inquiry in teacher education programmes would be of interest to complement its findings. Therefore, this review aims to analyse research on IBSE in science teacher education between 2000 and 2022 to answer the following research question:

How and with what outcomes is IBSE used in science teacher education?

To answer this research question, we focus on the general trends in the material and on how IBSE is implemented in research on teacher education when PSTs play the roles of either learners or educators. Based on the results, we provide recommendations for implementing IBSE in science teacher education and point out directions for future research. In the following section, we briefly discuss the arguments for IBSE in schools and in science teacher education before presenting our theoretical framework.

IBSE in the school science classroom

Crawford (2014) highlights several justifications for IBSE being part of classroom teaching, one of which is that it aligns with how pupils learn science. In a meta-study of 37 studies of IBSE in schools, Furtak et al. (2012) found generally positive learning effects. They found that IBSE had the greatest effect on learning when it involved pupils developing and justifying explanations, presenting and discussing their explanations in class and the teacher linking these to prior knowledge and academic concepts. Another justification for including IBSE is that it enables pupils to understand how science is conducted and that science itself is in constant development (Crawford, 2014). Both Rocard et al. (2007) and Crawford (2014) argued that inquiry can increase pupils' interest in science. Moreover, IBSE aligns with the aim of promoting pupils' skills in critical thinking and life-long learning (Crawford & Capps, 2018).

IBSE has been described as a student-centred approach (Bjønness & Kolstø, 2015; Crawford, 2014). Student-centred approaches have been criticised for being unguided or minimally guided, making them less effective than learning approaches that place a strong emphasis on teacher guidance (Kirschner et al., 2006). However, Hmelo-Silver et al., (2007) stressed that teacher guidance is crucial for IBSE to contribute to academic progress, to highlight conceptual knowledge and working methods, and to structure and focus the inquiry-based activities. A more recent study similarly indicated that sufficient teacher guidance in inquiry activities is positively associated with pupil performance, as measured through tests such as Trends in International Mathematics and Science Study (TIMSS) and PISA (Aditomo & Klieme, 2020). Furthermore, Zhang and Cobern (2020) argued that a central component of such teacher guidance should be to make science content available to pupils. This is in accordance with Rönnebeck et al. (2016), who argued that it is insufficient for pupils to carry out inquiry-based activities without linking them to scientific concepts.

The premise of the present work is that IBSE, when practised with appropriate teacher guidance in school science classrooms, is beneficial for pupils' science learning. Therefore, it follows that PSTs must also learn how to conduct inquiry and design inquiry-based learning situations to support science learning for their future pupils.

IBSE in teacher education

Teachers often teach the way they were taught themselves as pupils in schools (Huibregtse et al., 1994; Stuchlikova et al., 2013) and later as PSTs (National Research Council, 1996; Weld & Funk, 2005). However, many PSTs enter science teacher education without having experienced the inquiry-based approach (Windschitl, 2003). Thus, if teachers are to use inquiry methods, they must have met and used these practices in their teacher education (Sjøberg, 2019) and taken ownership of the inquiry-based approach (Stuchlikova et al., 2013).

Teacher education involves learning theoretical knowledge through campus-based activities and practising teaching in classrooms during school placement periods. Cochran-Smith and Lytle (1999) distinguished between knowledge-for-practice (the formal knowledge base that PSTs generally acquire through campus-based courses), knowledge-in-practice ('craft' knowledge acquired through experience in classroom settings) and knowledge-of-practice (an integration of the two, with a critical perspective on one's own practice) (Cochran-Smith & Lytle, 1999, p. 273). In the case of IBSE, PSTs need to develop all three kinds of knowledge.

The role of teachers in an inquiry-based approach is complex (Crawford, 2014; Dobber et al., 2017) and includes 'motivator, diagnostician, guide, innovator, experimenter, researcher, modeller, mentor, collaborator, and learner' Crawford (2014, p. 526). Therefore, science teacher educators need to provide examples of how to orchestrate IBSE in the classroom and explicitly model good science teaching for their PSTs (Lunenberg et al., 2007).

Theoretical framework

IBSE has been described and categorised in different ways, such as by its goals (Abrams et al., 2007) and by the degree of freedom contra guidance for learners in the inquiry process (Banchi & Bell, 2008; Herron, 1971). Anderson (2002) differentiated between scientific inquiry, inquiry learning and inquiry teaching. Scientific inquiry refers to researchers applying a scientific method to conduct research in science. Inquiry learning describes the process in which learners work with inquiry-based methods to understand scientific concepts and processes and the nature of science. Inquiry teaching describes the variety of ways in which teachers or teacher educators use inquiry as a pedagogical tool (Anderson, 2002). In the current review, inspired by Anderson (2002), we use the terms inquiry-based learning (IBL) to describe when PSTs experience inquiry as learners and inquiry-based teaching (IBT) when PSTs conduct and reflect on inquiry as teachers.

Furthermore, we use a categorisation of inquiry activity based on cognitive domains. Duschl (2008) suggested that science education should focus on three integrated domains: the epistemic domain, which is about how scientific knowledge is developed and evaluated; the conceptual domain, which concerns constructing an understanding of the concepts of science and reasoning scientifically; and the social domain, which is about communication and argumentation in scientific knowledge-building (Duschl, 2008). In their review of inquiry-based science teaching in school, Furtak et al. (2012) added a fourth category to Duschl's three categories – the procedural domain, which describes the practices involved in inquiry, such as asking scientifically-oriented questions, designing experiments and executing procedures.

Similarly, Crawford and Capps (2018) proposed a framework to describe the kinds of knowledge teachers need to engage pupils in inquiry practices. The main components of their framework are subject matter knowledge (which corresponds to the conceptual domain), knowledge of scientific practices (which corresponds to the procedural domain), knowledge of NOS (which corresponds to the epistemic domain) and pedagogical knowledge. As Crawford and Capps (2018, p. 13) included 'creating arguments, building models, and communicating findings' in their description of scientific practices, the social domain is also clearly included in their framework, although not as a separate component. 2018) focus on pedagogical knowledge may be seen as representing a fifth domain, which is relevant for teacher education, in addition to the four domains described by Duschl (2008) and Furtak et al. (2012). These five domains are used in the analytical framework of this article (see the Methods section). By using these domains, we place the current review in the context of previous works and also provide a link between research on IBSE in school and that in teacher education.

However, two things should be noted concerning the use of cognitive domains as a framework for describing IBSE in teacher education. First, the domains apply to science education more generally and are not restricted to IBSE; for example, a science class may work in the cognitive domain without undertaking inquiry-based approaches. Second, there is a considerable overlap between domains: learners may improve their epistemic understanding of science while dealing with procedural knowledge, and so on. Therefore, the categorisation of inquiry activities according to cognitive domains can never be absolute, and IBSE activities will often belong to several domains (Van Uum et al., 2016).

Methods

In this review, we have used database searches in line with a systematic review approach (Grant & Booth, 2009; Sutton et al., 2019). A systematic review 'seeks to draw together all known knowledge on a topic area' (Grant & Booth, 2009, p. 102) to provide a more comprehensive understanding of a particular phenomenon, in this case IBSE in primary and secondary science teacher education. Inclusion and exclusion criteria were used to select, organise, and analyse the included studies to address our research questions.

Database search and selection of studies

Studies were selected in a six-step process, starting with searches in three relevant databases in November 2019: Web of Science, Education Resources Information Center (ERIC), and Education Source, the two latter via EBSCOhost. In total, these three databases cover the width and depth of science education, representing both subject specific (i.e. Web of Science) and educational (i.e. ERIC and Education Source) databases. In the first step, three search strings were designed, as shown in Table 1 below. A challenge has been that a varied vocabulary is used in the literature to describe inquiry, teacher education and science. For example, terms such as inquiry learning, IBT, IBL and inquiry-oriented are all used. To embrace the different variants of inquiry, the first search string was set to include these variants. The second search string combined different variations of teacher education, and the third search string was about science. Natural science involves the various disciplines of biology, chemistry, and physics; hence, the third search string had to include all these variants. The search was completed in all the databases, with searches run for titles, keywords, and abstracts. The combined search process in ERIC and Education Source via EBSCOhost gave a result of 1090 hits. The Web of Science yielded 244 hits.

In the second step of the selection process, certain selection criteria were applied to narrow the search; the studies that were included are peer-reviewed online journal articles published in English from January 2000 to November 2019 (a later step included the period 2019–2022; see below). The results were imported into the application EndNote, and duplicates were removed both through the programme and manually. The total number of articles was reduced to 679.

Step three was to set up inclusion/exclusion criteria that were relevant for the purpose of this review (see Table 2). To investigate how IBSE is used in PST education (according to the research question), we decided to look at published research reporting on empirical studies. It was also important that the focus was on primary and secondary teacher

Table 1. The specific search in the web of science, ERIC, and education source databases.

Search	Search Term(s) in Web of Science, ERIC, and Education Source
S1	('inquiry-based' OR 'inquiry teaching' OR 'inquiry learning' OR 'inquiry-oriented')
S2	('teacher educat*' OR 'teacher training' OR 'teacher preparation program*' OR 'pre-service' OR 'preservice')
S3	('science' OR 'biology' OR 'chemistry' OR 'physics')
S1, S2 AND S3	S1 AND S2 AND S3

Table 2. Inclusion and exclusion criteria (inspired by Winje & Løndal, 2020).

Type of criterion	Criteria	Inclusion	Exclusion
Type of publication	Journal articles	X	
	Conference papers		X
	Reports		X
	Dissertations		X
	Books and book chapters		X
Publication period	January 2000 – December 2022	X	
Language	English	X	
	Other		X
Place of study	Worldwide	X	
Type of study	Empirical investigations	X	
	Literature reviews		X
	Theoretical reviews		X
Research methods	Qualitative	X	
	Quantitative	X	
	Mixed methods	X	
Participants in the study	PSTs in primary and/or secondary level	X	
	Pupils		X
	Teachers		X
	In-service teachers		X
	Teacher educators		X
Focus on the school subject	Science	X	
	Biology	X	
	Chemistry	X	
	Physics	X	
	Geoscience	X	
	Other (e.g. mathematics, history, language)		X
IBSE	In focus	X	
	As a context		X

education and PSTs in this programme, with PSTs as the subjects of investigation. IBSE is often implemented in teacher education through a science methods course (Abell et al., 2010; Sickel & Witzig, 2017), which may or may not include school placement (Sickel & Witzig, 2017), and the included articles included science methods courses both with and without school placement. Furthermore, this review focuses on inquiry in the school subject science, which includes biology, chemistry, physics, and parts of geoscience. We excluded studies where IBSE was just a context and not the main focus of the study (e.g. a study by Schwarz (2009) focusing on the method of design-based research (DBR), where IBSE was more of an example of where DBR was used). The first parts of the selection process were carried out by the first author, where the titles and keywords were studied and compared to the selection criteria, and then, the abstracts were studied. In cases of uncertainty, the studies were included until the next step. At the end of step three, 221 articles remained.

In the fourth step, we retrieved the full text of the remaining articles. These articles were divided between the three authors and read with a focus on assessing whether they should be included or not, based on the same criteria as those observed in step

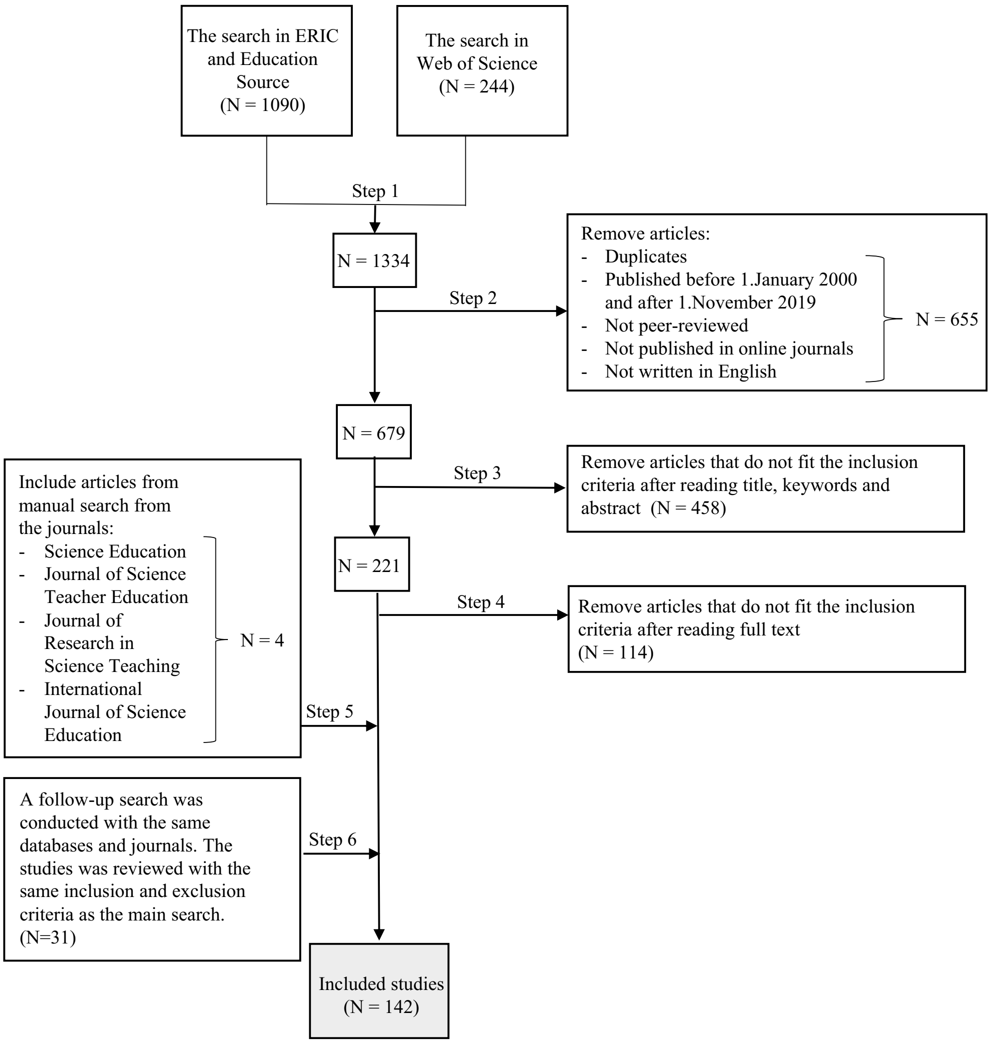

Figure 1. Flow chart of the process of selection of articles for inclusion in the present review.

three. In this process, we also assessed the scientific quality of the articles. Even though the articles were published in peer-reviewed journals, some were of poorer scientific quality. Articles were excluded if they had obvious shortcomings, such as insufficient descriptions of methods, unsupported claims, unclear or inconsistent language or lines of argument – in short, if they failed to fulfil general standards for scientific publishing. After the full text of the articles had been read, 107 studies remained.

In the fifth step, a manual search was conducted of the journals Science Education, Journal of Science Teacher Education, Journal of Research in Science Teaching, and International Journal of Science Education to make sure that relevant studies were included. These journals are highly regarded, and their scope is relevant to our inclusion and exclusion criteria. After this manual search, four relevant articles were added.

In the sixth and final step, a follow-up database search was conducted to find articles published between November 2019 (i.e. the time for the first search) and December 2022. The search was conducted in the same databases and journals as the first search and yielded 282 hits. After reviewing them according to the same criteria as earlier, 31 new studies were included in the literature review.

The overall process of selecting relevant studies is illustrated by the flow chart in Figure 1. The final number of included articles was 142; a complete list of all publications analysed in this review can be found in Appendix A.

Analytical framework

We developed an analytical framework along two dimensions, with categories chosen partly deductively, based on our theoretical framework, and partly inductively, based on the content of the reviewed articles. The first dimension was the distinction between IBL and IBT (inspired by Anderson, 2002). As described in the 'Theoretical Framework' section, we used IBL when PSTs were involved as science learners and IBT when they were involved in the teacher role. The IBT category was applied inclusively, in the sense that it included some papers that took PSTs through the entire process from doing IBL as learners to either a) reflecting as teachers on IBSE, b) designing IBSE lessons plans after participating in IBL or c) performing IBT in school placement after participating in IBL.

The second dimension was based on the four different domains described by Duschl (2008) and Furtak et al. (2012) (i.e. epistemic, procedural, conceptual, and social). In addition, building on 2018) framework, we defined a pedagogical domain covering articles that focused on general aspects of orchestrating IBSE in the classroom and how teacher education prepares candidates for this. This domain also encompassed PSTs' understanding of what IBT entails. Furthermore, a sixth domain was created inductively on the basis of analysis: the affective domain involved attitudes, beliefs, self-efficacy, and identity related to IBSE. This conceptualisation is in line with Jones and Leagon's (2014) description of teacher attitudes and beliefs, which includes teachers' beliefs about science, about teaching and about self (i.e. self-efficacy) as well as affective factors such as feelings about science, teacher identity, and more. Finally, a few articles were placed in the category 'other', which included, for instance, papers linking IBSE with particular kinds of technology or focused on metacognition or other aspects that were not included in the prior domains.

Table 3 gives an overview of the analytical framework and shows how many studies were categorised in each category. The categories IBL/IBT were mutually exclusive. During the categorisation into domains, we found that some of the studies could be placed in more than one domain. This was because either the domains were connected with each other, as discussed earlier, or the studies explored more than one aspect (e.g. both conceptual understanding and self-efficacy). Thus, some studies were categorised into more than one domain. Appendix A provides an overview of the specific categorisation for the various studies.

The included studies were analysed according to the analytical framework with the following procedure: All studies were categorised by at least two of the authors. The authors noted whether the studies should be categorised as IBL or IBT and which domain (s) the study included. After the categorisation, the authors compared their analysis with

Table 3. Analytical framework with descriptions of the categories and an overview of how many studies were categorised in each category.

	IBL: PSTs conduct inquiry as learners	IBT: PSTs implement and/or reflect on inquiry in the teacher role, or progress from conducting to teaching inquiry
Epistemic domain: Learning about science as inquiry and the nature of science (NOS)	11	6
Procedural domain: Developing learners' inquiry skills	25	23
Conceptual domain: Using inquiry to learn science content knowledge	24	5
Social domain: Constructing science knowledge and arguing from evidence in a social process while working with inquiry	2	2
Pedagogical domain: Teacher and student roles during IBSE; general aspects of teaching/learning through IBSE; PSTs' views on IBSE as a pedagogical approach; co-learning and co-teaching approaches; IBT during school practice placement	2	37
Affective domain: Attitudes, self-efficacy, identity, and beliefs related to IBSE	24	26
Other • Effect of IBSE on PSTs' metacognition skills, creative or critical thinking dispositions • Use of technology in IBSE	14	4

each other. If there were disagreements, the authors discussed them until reaching agreement. The categorisation of articles into domains was done according to the best of our understanding, but some degree of interpretation was involved, and some choices had to be made; thus, it would clearly be possible for other researchers to arrive at a slightly different result of the categorisation even when using the same framework. However, the goal of this categorisation was not to arrive at exact conclusions but to display and discuss some tendencies that our interpretation allowed us to see in the material.

Results

This review aims to provide an overview of how IBSE is used in teacher education, which is presented in three separate sections. The first section presents general trends in the included studies, the second gives descriptive summaries of how and with what outcomes IBSE is implemented with PSTs in the role of students (IBL), whereas the third section presents studies of PSTs in the role of teachers (IBT).

General trends in the included studies

The included studies displayed some general trends that are worth highlighting, such as the number of publications per year, location of the studies, methods applied, and what school level the teacher education programme aimed at. First, the number of studies published each year between 2000 and 2022 varied, but there was an increasing trend: In the time period 2000–2004, there were six publications, whereas in 2018–2022, the number had increased to 47. The largest group of studies were carried out in North America, with 64 of 142 from the USA. 51 of the studies were carried out in a European context; here, Turkey stands out with 27 studies, while the remaining 24 studies were conducted in Western Europe. Finally, 16 studies were conducted in Asia, four studies in Africa and one in Oceania. In terms of methods applied in the different studies, 83 studies used qualitative methods, 21 used quantitative methods and the remaining 38 used mixed methods. 81% of the qualitative studies and 41% of the quantitative or mixed method studies had less than 50 respondents. Finally, in regard to the school level the teacher education programme aimed at, 89 studies took place in science teacher education for primary, elementary or middle school, 24 focused on secondary school and 29 did not specify the school level. Details for each included study can be found in Appendix A.

In the following sections, we present different approaches to inquiry in science teacher education, sorted according to our analytical framework. Of the 142 included studies, 49% ($N = 69$) were categorised as IBL and the remaining 51% ($N = 73$) as IBT. In the categorisation into cognitive domains, most of the studies were categorised in the procedural, conceptual, pedagogical, or affective domains, and fewer in the epistemic and social domains. In describing our findings, we mention each of the articles at least once. As described in the 'Analytical Framework' section, 50 of the articles address more than one domain (see also Appendix A); these are described in the domain that is most prominent or where it contributes most to our review. Articles that we evaluate as contributing the most relevant information in regard to our research question are described in most detail.

IBL: when PSTs conduct inquiry as learners

In order to include IBSE in their future profession as teachers, it is recommended that PSTs need to experience this method in the role of learners (Stuchlikova et al., 2013; Weld & Funk, 2005). Of the 69 articles categorised as IBL, most were in the procedural ($N = 25$), conceptual ($N = 24$) or affective ($N = 24$) domains. Furthermore, eleven were in the epistemic domain, while only two were categorised in the social and pedagogical domains, respectively.

The epistemic domain

Eleven of the 69 IBL studies were placed in the epistemic domain. Many of these articles investigated PSTs' understanding of NOS (e.g. Kinyota & Rwimo, 2021; Ozgelen et al., 2013; Pérez & Díaz-Moreno, 2021). Several studies in this domain explored epistemic knowledge in combination with other domains. For example, Soulios and Psillos (2016) investigated primary PSTs' work with model-based inquiry and found that they improved their understanding of the nature and purpose of models in science as well as their conceptual understanding of optical phenomena. Crawford et al. (2005) looked at how inquiry-based software materials created a context for developing PSTs' understanding of NOS as well as of evolutionary concepts. Although the authors found that the PSTs demonstrated an increased understanding of NOS, they were alarmed by their 'less-than-viable notions of the nature of scientific work' (Crawford et al., 2005, p. 633), especially since the PSTs had already participated in several science methods courses and would enter the classroom soon after the study. Salter and Atkins (2013), on the other hand, compared PSTs' expressed views of NOS with the practices that the PSTs displayed when engaged in inquiry activities. Interestingly, the authors observed that whereas PSTs' expressed views on NOS changed little through the course, their observed inquiry practices improved in sophistication. Similarly, Pérez (2022) found that PSTs focused on aspects related to scientific inquiry rather than to epistemic knowledge.

Overall, the studies in this domain revealed that the PSTs struggled to understand NOS, and although their understanding was found to increase in some studies when NOS was given explicit attention (Ozgelen et al., 2013; Pérez & Díaz-Moreno, 2021), other studies revealed that IBL did not contribute significantly to PSTs' understanding (e.g. Akgul, 2006; Kinyota & Rwimo, 2021). Thus, experiencing IBL does not automatically enhance PSTs' understanding of NOS and there seems to be a need for more research on the specific ways in which IBL can contribute to PSTs' understanding of NOS.

The procedural domain

A large group of the IBL-related studies concerned the procedural domain, aiming to develop PSTs' inquiry skills. The majority of these studies were also categorised in another domain. The most common combination was with the conceptual and/or affective domains, but there were also other combinations, such as Ecevit and Kaptan (2022) who explored PSTs' scientific process skills, critical thinking dispositions, metacognitive awareness and views of NOS after participating in argumentation-based inquiry.

Generally, the studies categorised in the procedural domain focused on PSTs' work with the inquiry process or certain steps within it, such as posing questions (Cruz-Guzmán et al., 2017; Graves & Rutherford, 2012) or completing experimental activities (García-Carmona et al., 2016; García-Carmona, 2017; Hacıeminoğlu et al., 2022; Wang et al., 2022). Choosing a topic for investigation and formulating 'researchable' questions are crucial steps in any inquiry process, and require experience and training. Cruz-Guzmán et al. (2017) investigated the questions elementary PSTs posed when they designed experimental activities in science. Their study showed that many of the PSTs' initial questions were unclear, unspecific or difficult to research. However, after explicit instruction and a round of peer assessment using explicit criteria, the majority of questions posed were clear and coherent, often asking for relationships between measurable variables. In a later study, Cruz-Guzmán et al. (2020) investigated how PSTs formulated questions when designing inquiry-based activities, using a taxonomy of low- and high order questions. They recommended that for PSTs to train their ability to formulate higher-order, researchable questions, they need experience with question posing across a wide variety of science topics. Furthermore, García-Carmona et al. (2016) investigated PSTs' inquiry skills and identified considerable challenges for the PSTs in many stages of the inquiry process, such as formulating hypotheses and choosing a strategy for investigation. They pointed to the challenges for teachers to implement inquiry with pupils if they themselves are insufficiently educated in the different stages of an inquiry process. Following up on this, García-Carmona (2017) analysed PSTs' capabilities to complete an experimental activity set as guided inquiry and found that the PSTs were able to complete the activity satisfactorily. Thus, García-Carmona (2017) emphasised the usefulness of experimental activities focusing on procedure and of implementing such activities with increasing difficulty throughout the course; the author also recommended more explicit instruction in how to perform a science inquiry.

Several of the articles in the procedural domain reported on favourable outcomes of IBL sequences related to scientific process skills (Irwanto et al., 2019; Sen & Vekli, 2016; Tatar, 2012; Valls-Bautista et al., 2021; Yakar & Baykara, 2014). One example was given by Oh (2011), who described an abductive inquiry model in which PSTs worked on constructing scientific explanations for the path of a typhoon. According to the author, 'abduction is a backward-directed inference, which proceeds from an effect to a cause' (Oh, 2011, p. 427). He described how PSTs worked meaningfully through the different phases of the inquiry and remarked that the abductive inquiry process functioned better when the PSTs had a solid knowledge base in science. Lustick (2009), on the other hand, conducted an investigation of a science education methods course where the goals were to help PSTs acquire the skills, knowledge and dispositions necessary to foster learning through inquiry. However, the project failed to achieve its learning goals; the intervention was not successful in promoting PSTs' inquiry skills or their attitudes and beliefs about IBSE. Lustick (2009) therefore asked whether it is at all reasonable to expect PSTs to not only learn about inquiry, but use it to teach their pupils.

Other articles in the procedural domain also allowed the PSTs to participate in IBL and studied their perceptions of IBSE and intentions to include it in their future teaching (Acarli & Dervişoğlu, 2021; Feyzioglu, 2019; Kapucu, 2016; Morrison, 2008). Among these, Morrison (2008) allowed elementary PSTs to perform an individual, in-depth science inquiry project and reported that, after this experience, they displayed an understanding of the inquiry process and intention to use inquiry in their future teaching. This finding showed the importance of giving PSTs first-hand experiences with IBL as learners and linking this experience to reflections and plans for implementing IBT as teachers. Bruckermann et al. (2017) investigated how cognitive, metacognitive, and multimedia support scaffolded PSTs' development of experimentation competency and found that the combination of scaffolding approaches did not necessarily enhance learning but could, rather, contribute to cognitive overload.

To sum up, the papers in the procedural domain show that PSTs can increase their inquiry skills when using IBL, but this does not happen automatically. There are challenges, and these studies recommend that the PSTs need explicit instruction about the various phases and practices that are a part of IBL. Additionally, the PSTs need sufficient content knowledge and scaffolding to produce good learning outcomes of the IBL-related activity in the procedural domain.

The conceptual domain

Another large group of articles concerned conceptual learning through IBL, where topics from all scientific disciplines were represented. Most of these articles were in physics ($N = 11$), focusing on topics such as light (Muñoz-Franco et al., 2020; Soulios & Psillos, 2016), electricity (Önder et al., 2018), magnetism (Okulu & Ünver, 2018) or physics more generally (Bryant, 2006). Furthermore, there were articles in biology ($N = 4$) and chemistry ($N = 5$), with topics such as evolutionary concepts (Crawford et al., 2005), fish anatomy (Kukkonen et al., 2016), plant processes (Thompson et al., 2016), chemical reaction rate (Jeenjenkit et al., 2011), surface tension (Gencer & Ekici, 2022), organic chemistry (Aidoo et al., 2022) and change in matter (Kazempour & Amirshokoohi, 2013). There were also articles in environmental sciences (Namdar, 2018) and geosciences (Nugent et al., 2012).

The articles in the conceptual domain were often related to the effect of a specific IBL-related approach. Isabelle and de Groot (2008), using the inquiry-based 'Itakura method', sought to mediate PSTs' alternative conceptions of the concept 'expansion of solids when heated'. The Itakura method is a peer discourse, whereby students share ideas, question one another and debate as they struggle to negotiate meaning about a science concept (Itakura, 1967). The authors found that the method had a positive effect on PSTs' learning, and the effect prevailed after three months. They ascribed the method's success partly to its support of learner discourse in the development of conceptual understanding. Similarly, Buyruk and Bekiroglu (2018) found that an explicit focus on modelling in inquiry work facilitated PSTs' conceptual learning about dynamics, while Ucar and Trundle (2011) and Ucar et al. (2011) concluded that a guided inquiry approach was superior to more traditional teaching approaches for enhancing PSTs' understanding of tides.

One study in the conceptual domain focused on the importance of teacher guidance in IBL to facilitate subject understanding. Plummer et al. (2010) found that most of their sample of PSTs working with an open inquiry activity focusing on celestial motion improved their understanding; however, the authors also observed that more guidance, particularly in the later phases of the open inquiry process, might have improved the results further.

Remaining in the conceptual domain, Sanger (2007, p. 1038) concluded that PSTs taught through an inquiry approach learned chemistry content 'at least as well' as PSTs experiencing more traditional instruction. Weld and Funk (2005) looked at PSTs involved in an inquiry-based course in biology and noted improvements in their self-perceived subject matter learning as well as in curriculum development competency and pedagogical skills, indicating that undertaking IBL prepared PSTs for IBT. Similarly, Namdar (2018) found that IBL activities about global climate change were related to gains in conceptual understanding as well as in PSTs' preparedness to teach the topic. Finally, Nugent et al. (2012), in the field of geoscience, exposed PSTs to inquiry-oriented field experiences and compared them with PSTs following a traditional, classroom-based course. They found that the PSTs who had worked with inquiry in the field had higher scores on a range of parameters related to conceptual understanding, science attitudes, inquiry skills and self-efficacy for teaching science. In line with many other authors, Nugent et al. (2012) remarked that 'Content knowledge is a necessary prerequisite, but it must be complemented by instruction and experiences that foster understanding of how to design and deliver inquiry lessons' (p. 526).

In general, all studies in the conceptual domain reported that increased subject matter understanding resulted from IBL activities. Most of these studies, however, did not have a design that allowed comparisons between the conceptual learning gain from the IBL interventions and other instructional strategies such as for instance a more traditional lecture format. Also, most of the studies had relatively few participants, with the exception of the study by Otto et al. (2012), who demonstrated conceptual learning gains for a large sample of PSTs following an entire inquiry-based science education programme.

The social domain

Two articles were categorised in the social domain, which is about communication and argumentation. These two articles focused on how PSTs develop argumentation skills. Gurel and Suzuk (2017) used the structure of arguments and scientific credibility model developed by Puvirajah (2007) to analyse the quality of PSTs' argumentation when working with model rockets. They found that the PSTs had low quality of argumentation, but that argument-based inquiry-oriented laboratories could support and promote argumentation. Ozdem et al. (2013) analysed and classified the argumentation performed by PSTs as they worked with inquiry tasks in the laboratory. They found that PSTs employed a diversity of argumentation schemes and claimed that inquiry-based laboratory settings may be a suitable arena for PSTs to develop their capacity to build scientific arguments. The authors pointed out that PSTs must 'engage in high quality argumentation themselves before they can support students' successful argumentation' (Ozdem et al., 2013, p. 2580).

As will be addressed in the Discussion, we find it thought provoking that the number of studies within the social domain of IBL in teacher education is so low and that there are no studies focusing on communication and collaboration, given the central place of argumentation as well as communication and collaboration in IBSE, as described in the Introduction.

The pedagogical domain

Since the IBL articles describe PSTs working with inquiry as learners, not as teachers, it was not expected to find a large number of IBL articles in the pedagogical domain, and indeed, only two articles were placed in this category. Both of these studies were qualitative and conducted in a European context. Glackin and Harrison (2018) investigated PSTs' views of IBL and inquiry opportunities after being introduced to IBL in a botanical garden, whereas Akgul (2006) investigated PSTs' understanding of teaching science while they attended an inquiry-based science course with a particular emphasis on NOS, teachers' role and students' role. Akgul (2006) recommended that PSTs need to be engaged in inquiry-based activities as learners and that teacher education must be designed to model IBT, exemplifying for the PSTs what IBSE can look like in the classroom. This is in line with 2007) recommendation that teacher educators need to explicitly model good science teaching for the PSTs.

The affective domain

In the affective domain, we found several studies that addressed PSTs' attitudes and beliefs related to IBSE in addition to a focus on one or more of the other domains. For instance, Yakar and Baykara (2014) found that PSTs involved in IBL improved their attitudes towards science experiments as well as their scientific process skills and creative thinking levels. Similarly, Sanger (2008) observed that having experienced IBL as a student impacted on PSTs' notions of NOS and on their interest and confidence in using inquiry-based approaches to teach chemistry.

Other studies in the affective domain investigated PSTs' self-efficacy, and several of them reported improvements in PSTs' self-efficacy related to laboratory work (Acarli & Dervişoğlu, 2021; Sen & Vekli, 2016) and teaching (Docherty-Skippen et al., 2020; Richardson & Liang, 2008; Rohaeti & Prodjosantoso, 2020). A study by Avery and Meyer

(2012) described an inquiry-based biology course and investigated the PSTs' self-efficacy using survey instruments as well as interviews. They found that a considerable group of PSTs obtained positive results in terms of self-efficacy for science and science teaching; however, there was also a sub-group of students who had a negative development through the course. This points to the importance of investigating background factors shaping students' experiences of and benefit from different kinds of interventions and course designs and calls attention to providing varied learning experiences to suit the backgrounds, interests and needs of diverse groups of PSTs.

Yet other studies focused on how the PSTs' attitudes and beliefs changed during courses focusing on IBSE (e.g. Duran et al., 2004; Kıran, 2022). Duran et al. (2004) investigated PSTs' views of the learning environment in an inquiry-based physics course following the 5E model, which is a framework for conducting IBSE through five phases: engage, explore, explain, elaborate and evaluate (Bybee et al., 2006). The authors found that PSTs first felt frustrated but later embraced the inquiry method and found it helpful both in understanding the concepts and using the method as prospective teachers. Pilitsis and Duncan (2012) looked at how PSTs' beliefs regarding teaching and learning developed through working with IBL activities in a science methods course. They observed a change in attitudes from a more teacher-centred to a more student-centred orientation. Tessier (2010) found that after PSTs participated in an inquiry-based introductory biology course, they expressed more favourable attitudes to biology and intentions to use IBSE in their future professional work as teachers. Riegle-Crumb et al. (2015) found that PSTs' attitudes (confidence, enjoyment, anxiety, and perceived relevance) to science improved considerably after participating in an inquiry-based science course, whereas the attitudes of a comparison group declined. Thus, the authors suggested that interventions such as their inquiry-based science courses might help break the negative cycle of teachers propagating their negative science attitudes to their pupils. Since teachers' attitudes towards science and science teaching are important for the quality of instruction their pupils receive, this study illustrates that teacher education needs to attend to PSTs' attitudes as well as their skills and knowledge.

To sum up, the studies in the affective domain point to the important role of attitudes and self-efficacy for teachers' competence development related to IBSE. Most of these studies reported improved attitudes to science or increased self-efficacy for using IBSE. However, these studies also accentuate that affective outcomes of IBSE in teacher education are shaped by a range of background factors and previous experiences; these mechanisms remain to be explored in more detail.

Other

14 IBL studies were placed in the category 'other'. One strand of papers within this category focused on how technology can support IBL (Arabacioglu & Unver, 2016; Bruckermann et al., 2017; Crawford et al., 2005; Inel-Ekici & Ekici, 2021; Kukkonen et al., 2016; Schmidt & Fulton, 2017). In their study of PSTs' experiences of the use of a Wiki to scaffold an IBL approach to the dissection of a fish, Kukkonen et al. (2016) found that the Wiki was not directly related to the experienced benefit, but that it had an indirect effect as the use of digital images for visualisation and peer support in small groups was seen as beneficial. Furthermore, Arabacioglu and Unver (2016) explored laboratory practices that used mobile learning and found that they could support PSTs' process skills. Finally,

Schmidt and Fulton (2017) planned a technology-rich digital unit for PSTs about moon phases and found both appropriate and inappropriate use of technology. They argued that the PSTs showed lack of technological literacy, since they did not know when they should, or should not, use technology, and when to choose one type over another.

The remaining articles in this category studied the effectiveness of IBL in relation to metacognition (Asy'ari et al., 2019; Ecevit & Kaptan, 2022), creative thinking (Yakar & Baykara, 2014) and critical thinking (Arsal, 2017; Ecevit & Kaptan, 2022; Irwanto et al., 2019; Karea et al., 2021; Prayogi & Verawati, 2020; Verawati et al., 2020). The studies focusing on the effect of IBL in relation to metacognition or critical thinking displayed mixed results. Arsal (2017) investigated the impact of IBL on PSTs' critical thinking dispositions and found that the experimental group did not display statistically significant improvement compared to the control group. On the other hand, Asy'ari et al. (2019) and Irwanto et al. (2019) found in their studies that metacognition and critical thinking, respectively, improved for PSTs who had participated in IBL.

IBT: when PSTs implement and/or reflect on inquiry in the teacher role

Of the 73 articles concerning PSTs implementing inquiry in the role of teacher and/or constructing or evaluating IBT approaches aimed at pupils, most were categorised in the procedural ($N = 23$), pedagogical ($N = 37$) or affective ($N = 26$) domains. Only 13 in total were in the epistemic, conceptual, or social domains.

The epistemic domain

Six studies were categorised in the epistemic domain (Eick, 2000; Haefner & Zembal-Saul, 2004; Lee & Shea, 2016; Lotter et al., 2009; Valente et al., 2022; Özer and Sarıbaş, 2022). Eick (2000) examined a group of PSTs' views of inquiry and NOS after participation in two methods courses and teaching during school placement. The authors observed that inadequate understanding of NOS may limit the PSTs' repertoire of inquiry activities in the classroom. Similarly, Özer and Sarıbaş (2022) also explored PSTs' understanding of scientific inquiry and scientific practices after participating in teaching addressing the two issues, including microteaching. Their found that the teaching had positive impact on the PSTs' understanding of scientific inquiry and scientific practices, but that the PSTs still had inadequate understanding of some aspects of inquiry after the treatment.

Haefner and Zembal-Saul (2004) examined PSTs' learning about scientific inquiry when they first participated in IBL and thereafter observed and conducted IBT with pupils. They found that the PSTs improved their understanding of scientific inquiry and the experimental aspects of science. Furthermore, the PSTs' prior experiences as science learners were also challenged, and their views changed from a teacher-centred approach, focusing on themselves as teachers who were expected to provide correct answers, to a learner-centred approach, in which the pupils' questions and exploration became a central feature. This shift was parallel to a shift in the PSTs' thinking about science, from a view focusing on the products of science to one on science as a process. Similarly, Lotter et al. (2009) followed PSTs through a methods course that included school placement and investigated how their views on NOS and inquiry-based instructional practices changed. They found that the PSTs' NOS conceptions grew more sophisticated through the course and that their conceptions of IBT and ability to implement it with pupils improved. The authors attributed the success to a close interplay between PSTs doing coursework, observing mentor teachers, and implementing and reflecting on IBT in classrooms. They argued that the key to improving PSTs' IBT skills is to involve them in 'guided reflection' that is directly linked to their teaching experience (Lotter et al., 2009, p. 574).

Overall, the papers in the epistemic domain indicate that many PSTs enter teacher education with relatively poor preparation in the epistemic aspects of inquiry, but that it is possible to develop their level of epistemic reflection through targeted teaching and learning experiences where there is interplay between theoretical input, classroom teaching experience and guided reflection. However, the small number of articles in this category suggests that more studies are needed concerning how epistemic aspects of inquiry are implemented in science teacher education.

The procedural domain

Several of the IBT articles were related to the procedural domain, investigating different approaches helping PSTs to structure inquiry activities in the classroom. One strand of papers addressed PSTs' inquiry skills and attitudes through letting them design or evaluate teaching approaches or learning materials for IBT in school (Duncan et al., 2010; Forbes, 2013; Saribas, 2015; Seung et al., 2014). Some of these articles highlight that PSTs struggle with one or more parts of the inquiry process. Seung et al. (2014) investigated PSTs' understanding of six essential features of IBT and concluded that PSTs need more training in recognising and implementing central features of the inquiry process in the classroom. Saribas (2015) recommended that PSTs be given training in asking suitable questions as part of the inquiry process. Duncan et al. (2010) pointed to a suitable model for how to build up PSTs' skills in designing IBT: critiquing and adapting existing curriculum materials and designing new materials for inquiry-based science teaching.

Another strand of papers (Enugu & Hokayem, 2017; Goldston et al., 2013; Qablan & DeBaz, 2015) was related to specific instructional frameworks, in particular the 5E model. For example, Enugu and Hokayem (2017) studied challenges PSTs faced when implementing the 5E model and found that they had insufficient content knowledge and hence had trouble with the explain and elaborate phases. The PSTs also had difficulties in managing the time to teach through the 5E model. In addition to the 5E model, some other instructional frameworks were presented and discussed in the papers. By using a guided inquiry and modelling instructional framework called 'Engage-Investigate-Model-Apply' (EIMA), Schwarz and Gwekwerere (2007) allowed PSTs to experience, learn about and teach inquiry, with particular attention to modelling in science. The 'Steps to Inquiry' (SI) framework was described by Rees et al. (2013), who concluded that it was effective in supporting PSTs to enact open inquiry in the classroom with pupils.

A third strand within the procedural domain focused on specific ways of orchestrating inquiry in the classroom (Baxter et al., 2004; Britner & Finson, 2005; Nivalainen et al., 2013; Shively & Yerrick, 2014; Syer et al., 2013; Varma et al., 2009; Zulfiani & Herlanti, 2018). Zulfiani and Herlanti (2018) recommended including both guided and open IBSE activities in science teacher education in order to make PSTs more independent and creative when planning inquiry-based activities. Baxter et al. (2004) focused on the transition from 'doing science' to 'teaching science' by inquiry. In their study, PSTs first conducted a research project related to the Great Salt Lake and thereafter converted their research project to a teaching unit which they then taught in local schools. The authors also described how the intervention was assessed using several data sources and assessment methods. A challenge was that PSTs struggled to transfer their experiences of 'doing' science (IBL) to actively using these experiences in designing teaching and learning activities (IBT). For instance, they had challenges concerning assessment, relation to scientific literacy, and attention to cultural issues. This observation led to changes in the intervention to make the PSTs better able to 'dissect' and discuss inquiry lessons and to handle the transition from 'doing' science to teaching science by inquiry. This study is an example of a systematic intervention to let PSTs experience the whole continuum from 'doing' IBL to implementing IBT, and it highlights the importance of having a reflection with the PSTs on the transition from 'doing' to 'teaching'. Similarly, Varma et al. (2009) investigated how a methods course and field experience influenced PSTs' understanding of IBSE and emphasised the fruitful relationship between PSTs being involved in inquiry as students in their methods course and concurrently observing or conducting inquiry with pupils in classrooms during school placement. More problematic experiences were reported by Britner and Finson (2005), who investigated the degree to which designing and completing inquiry investigations influenced the ability of PSTs to design science lessons using inquiry approaches – and, in turn, their confidence and motivation for IBT. They found that the PSTs had positive views of IBL before school placement but found it difficult to implement.

To sum up, the papers in the procedural domain highlighted challenges that PSTs meet in the different phases of IBT, for instance that they need sufficient content knowledge to plan and conduct IBT. Some of the most interesting papers describe PSTs' progression from engaging in IBL in the role of student to planning and conducting it in the role of teacher. Such comprehensive approaches appear promising for preparing PSTs for thoughtful implementation of IBT, as they may not only prepare PSTs for IBT but give more general support for their attitudes to science, as well as their skills, confidence, and intention to teach science through inquiry. Another promising approach is to take PSTs through a process from critiquing existing IBT resources through adapting such resources to finally designing their own IBT resources for use in the classroom. Relatively few of the reviewed papers described such comprehensive learning progressions for PSTs.

The conceptual domain

Four articles explored specific areas of conceptual understanding or science content learning in connection with IBT (Leonard et al., 2009; Luera et al., 2005; Nivalainen et al., 2013; Plummer & Ozcelik, 2015). Luera et al. (2005) explored the relationship between PSTs' science content knowledge and their ability to design IBT in the form of lesson planning and found a significant positive relationship. Through quantitative investigations of a relatively large sample ($N = 234$), they found that PSTs with better science content knowledge were also better at designing inquiry teaching following the 5E model. Leonard et al. (2009) followed 12 PSTs over a two-year period of their education and studied their earth science knowledge as well as their IBT skills. They found mixed results, with only moderate gains in PSTs' science knowledge and IBT skills. Plummer and Ozcelik (2015) studied PSTs who had worked with astronomy investigations and then designed inquiry-based astronomy teaching sequences for pupils. They found that PSTs' astronomy content knowledge correlated positively with their construction of coherent inquiry sequences for pupils, again highlighting the importance of sufficient content knowledge for PSTs to be able to implement quality IBT.

The social domain

The only articles categorised in the social domain are two studies conducted in Finland (Hiltunen et al., 2016, 2021). Hiltunen et al. (2021) examined what kind of questions PSTs ask pupils during school practice. The results revealed that the PSTs mainly focused on the conceptual outcomes of inquiry-based lessons. The authors recommend that PSTs' questioning practice needs to be developed more towards higher-order questioning, especially questions concerning analysis, synthesis, and evaluation. Hiltunen et al. (2016) examined five PSTs and their classroom talk patterns in the context of inquiry-based biology lessons using the framework of Mortimer and Scott (2003) as analytical tool. The authors classified more than half of the PSTs' talk as authoritative and less than a quarter as dialogic. Moreover, the PSTs seldom asked pupils to describe their reasoning. The authors concluded that teacher education needs to scaffold candidates in how to orchestrate interactive classroom discussions when carrying out inquiry-based teaching. This is particularly important since research has demonstrated the central role of argumentation to promote science learning and the importance of appropriate teacher scaffolding in this process (Zhang & Cobern, 2020).

The pedagogical domain

Naturally, since the papers in the IBT category concern PSTs in the teacher role, many are in the pedagogical domain, describing PSTs' general views on inquiry teaching and their experiences of enacting it in classrooms (e.g. Cian et al., 2017; Hiltunen et al., 2021). Cian et al. (2017) investigated how PSTs developed their perceptions of inquiry and of themselves as teachers during school placement and noted that PSTs specifically needed training in how to constructively make use of feedback from mentors in the process of planning IBT. To strengthen this reflection component of training for IBT, the authors recommended requiring PSTs to submit written reflections in which they account for how they used feedback as part of their planning of IBT lessons.

Other papers explored how PSTs' past experience and teaching philosophies affected their IBT (Biggers & Forbes, 2012; Eick & Reed, 2002; Hamed et al., 2020; Papaevripidou et al., 2017). Eick and Reed (2002) found that PSTs' personal learning histories impacted their teaching identity and role perception related to implementing IBT in science classrooms. Biggers and Forbes (2012) studied PSTs participating in a science methods course focusing on developing lesson plans and teaching elementary pupils about essential features of inquiry. They noted that the PSTs developed their understanding on the role of teacher support and how to scaffold pupils during inquiry in the classroom. Hamed et al. (2020) also analysed the progression of PSTs' learning during teacher education. They found that the PSTs progressed from a traditional orientation to a more inquiry-based orientation and argued that it is important to focus on progression in how IBSE should be implemented in teacher education.

Some studies highlighted the importance of engaging PSTs in reflective group discussion to develop their views of IBT (McDonald et al., 2019; Yoon et al., 2013; Zhou & Xu, 2017). For instance, Yoon et al. (2013) allowed PSTs to go through a process of lesson planning and peer teaching, followed by teacher educator feedback and reflective group discussion, a second round of peer teaching, a second round of peer and instructor comments and, finally, individual reflections through journal writing and a group interview. The authors concluded by recommending that PSTs engage in reflective group discussions and have the opportunity to re-teach lessons as central experiences supporting students' inquiry practices. Zhou and Xu (2017) applied a microteaching lesson study in a methods course which allowed the PSTs to implement inquiry teaching with their peers and reflect on this experience and their understanding of inquiry. The authors concluded that the microteaching lesson study was a promising way to develop the PSTs' understanding of inquiry and their IBT skills, and they pointed out that the approach also offered opportunities of formative assessment.

Several articles within this domain put a particular emphasis on challenges related to IBT (Hayes, 2002; Krämer et al., 2015; Meyer et al., 2013; Nawanidbumrung et al., 2022; Yoon et al., 2012). Meyer et al. (2013) grouped the challenges into three major categories: extrinsic, pedagogical, and intrinsic. Time was found to be the most significant extrinsic challenge, whereas pedagogical challenges were related to determining the content and extent of an IBSE project. Finally, intrinsic challenges were identified as making the task substantive and authentic enough, difficulties with the social context, and representation of scientific phenomena in the classroom. Yoon et al. (2012) studied the challenges encountered by PSTs when implementing IBT during their school placement. They noted challenges relating to the inquiry teaching practice (e.g. developing pupils' ideas and curiosity and scaffolding pupils in interpreting and discussing their data) as well as challenges relating to the PSTs' understanding of inquiry (e.g. 'the meaning and role of hypotheses in the inquiry process as distinct from simple prediction' (Yoon et al., 2012, p. 604)).

A specific challenge that several articles addressed is the tensions between the theoretical perspectives the PSTs learn at university and the science teaching they experience in school placement (Bansal, 2021; Binns & Popp, 2013; Yerrick et al., 2008). Binns and Popp (2013) found in their study that the PSTs had positive views of IBL before school placement but found it difficult to implement. Furthermore, there was a disconnect between what they learned on campus and in school placement; the mentors did not include IBL to any extent, and the PSTs reported that they closely followed the teaching format of their mentors since they regarded the mentors as successful teachers. Although PSTs gained little experience of inquiry teaching and learning through their school placement, they continued to regard inquiry instruction as favourable for learning science but saw classroom management and curriculum demands as preventing its use. This illustrates the importance of tying together campus-based instruction and school placement to build PSTs' IBT skills and self-efficacy.

To relieve the tension between campus and school placement experiences, Greca (2016, p. 791) suggested constructing a 'third discursive space' which

> 'appears when preservice teachers are involved in specific activities that allow them to contrast the discourses of theoretical knowledge taught at university with practical knowledge arising from their ideas on science and science teaching and their observations during classroom practice.'

Along similar lines, Gilbert (2009) described a research design where PSTs 1) wrote philosophy statements about their teaching beliefs, 2) produced lesson plans, 3) discussed these plans with mentors, 4) conducted their teaching and 5) reflected on their teaching. The author remarked that the philosophy statement could be a powerful tool to help PSTs 'stay focused on the kind of science teachers they wished to become' (Gilbert, 2009, p. 437).

Other authors have tried to address the gap between campus and school placement through co-learning (Gunckel & Wood, 2016) and co-teaching (Eick & Dias, 2005; Hwang et al., 2018; McCullagh & Doherty, 2021). Gunckel and Wood (2016) let PSTs and mentor teachers learn together through co-learning tasks in which they applied principles of science inquiry to analyse and modify science curriculum materials. Working together on these tasks supported the PSTs in seeing connections between what they were learning in their science methods course and the classroom teaching context, and it supported mentor teachers in getting to know the principles of IBSE. The 'co-teaching' approach described by Eick and Dias (2005) is similar, as two PSTs and an experienced middle school teacher taught together. The PSTs submitted reflective narratives each week, which ended with a question. Their fellow students and instructor replied to these postings, which were used to describe and trace the PSTs' development during co-teaching.

A small group of the articles in the pedagogical domain describe IBT in cross-curricular contexts, such as science and mathematics projects (Magee & Flessner, 2012) or sustainable development (Amos & Levinson, 2019), or in connection with context-based teaching (Herranen et al., 2019) or literacy (Nesmith et al., 2017).Finally, two studies conducted by Nhlengethwa et al. (2020) and Nhlengethwa et al. (2021) explored PSTs' competencies using the cognitive domains given by Duschl (2008) and Furtak et al. (2012) during IBT. These studies found that PSTs emphasised the procedural, conceptual and social dimensions of IBSE, whereas the epistemic domain was given little priority. The authors suggested that teacher education must ensure that all these dimensions are included to give the PSTs comprehensive experiences with IBSE.

As the above paragraphs illustrate, the pedagogical domain was prevalent among the reviewed papers in the IBT category. The studies pointed out some challenges with IBT in science teacher education. Perhaps the most serious of these relates to the tension between the campus-based parts of the education and classroom practice. Providing ample opportunity for PSTs to reflect on theoretical as well as practical aspects, both with each other and with science teacher educators and mentor teachers, appears the most promising way forward.

The affective domain

Many of the IBT articles belong in the affective domain, describing PSTs' self-efficacy, identity, or attitude to IBT (e.g. Del Greco et al., 2018; Ma et al., 2022; Richardson et al., 2014; Smolleck & Yoder, 2008; Soprano & Yang, 2013). Several papers describe how PSTs' self-efficacy for teaching science as inquiry can be supported through a carefully designed methods course (e.g. Fazio et al., 2010; Lee & Shea, 2016; Varma, 2011). In these studies, the PSTs' self-efficacy increased during the methods course, and in some cases, the PSTs' perceptions of the teacher role developed from a teacher-focused to a more learner-focused view (Del Greco et al., 2018; Soprano & Yang, 2013). However, Richardson et al. (2014) looked at PSTs' self-efficacy for environmental education during an inquiry-based science intervention and found that it increased over the first half of the intervention and then decreased towards the end. They recommended further research into PSTs' experiences of the different instructional contexts in such interventions to understand better how their self-efficacy develops.

Other studies within the affective domain investigated how more informal teaching settings affected PSTs' self-efficacy (e.g. Kim, 2010). Cartwright et al. (2014) explored how a programme that was created to support PSTs with guided inquiry impacted their ability to confront barriers to teaching science. The PSTs taught in an after-school programme, and the study is an example of how PSTs can learn science instruction and at the same time benefit the community. Participants increased their self-efficacy in science and in science teaching as a result of the experience. Leonard et al. (2011) looked at PSTs' beliefs related to IBT and how these interplayed with their inquiry-based practices when implementing IBT in an urban setting. They found that the majority of the PSTs either sustained or improved their self-efficacy during this experience. Leonard et al. (2011) further highlighted the importance of vicarious and mastery experiences for PSTs to be able to design and conduct IBT.

Some studies highlighted the PSTs' attitudes to IBT in a school setting (e.g. Bhattacharyya et al., 2009; Kang et al., 2013). Qablan et al. (2009) investigated three PSTs' attitudes to, and intentions to use, IBT as teachers. They found that although respondents expressed favourable attitudes to IBT and considered it a valuable approach, some expressed preferences for using more traditional teaching approaches. This finding highlights the need for PSTs to familiarise themselves with IBSE throughout their education in order for them to take ownership of the approach. Hayes (2002) described how PSTs needed to articulate their identity and role as a teacher in the process of developing the skills to implement IBT in classrooms. The PSTs in Hayes' (2002) study developed their teacher identities through their struggles in the classroom. Positive affective outcomes of IBT experiences in terms of PSTs' science identity and science teacher identity were reported by Wang and Sneed (2019) and Wang (2020).

Summing up, the papers in the affective domain represent mixed results, perhaps illustrating how details of the context may determine PSTs' outcome in terms of affective variables after working with IBT. Nevertheless, these papers point to the importance of PSTs developing self-efficacy for IBT and an identity as an inquiry-based teacher. Since teachers' emotions and identity shape their enactment of teaching in the classroom (Uitto et al., 2015), teacher education needs to pay attention to supporting PSTs' identity development related to IBSE.

Other

Four IBT articles were categorised in the domain 'other'; these focused on how IBT could be enhanced through the use of technology (Aydin, 2019; Hakverdi-Can & Sönmez, 2012; Park et al., 2022; Shively & Yerrick, 2014). For instance, Shively and Yerrick (2014) explored the role of two educational technology courses in promoting IBT. They found that the PSTs' prior teaching and learning experiences were insufficient for using technology effectively, but that the PSTs' lesson plans and artefacts demonstrated a progression towards more open inquiry and giving technology a central role in teaching.

Discussion and conclusion

This review aimed to contribute to a better understanding of how and with what outcomes IBSE is used in science teacher education. In this section, we comment on some overall trends in the reviewed articles and then discuss the findings, structured according to our two-dimensional framework. Thereafter, we offer recommendations for integrating IBSE in science teacher education, recommend areas for further research and development, reflect on the limitations of this review, and conclude the article.

Overall trends in the reviewed articles

We would like to briefly comment on five trends in the reviewed articles. First, there is an increasing trend in the number of studies published each year, and second, the review showed a Western dominance with a total of 115 of the 142 studies from the US and Europe. Fewer articles were from Asia, Africa and Oceania and there was an absence of articles from South America. A geographically and culturally broader base of research is needed to provide an overview of how IBSE develops in teacher education in different contexts.

Third, in terms of the methods applied, the majority of the qualitative studies were typically conducted in one or two classes of PSTs within a limited part of the teacher education programme, typically the 'methods course'. The results from these small-scale, qualitative studies may possibly be context-bound and may not necessarily be transferable to other contexts. Fourth, the studies were mostly conducted in primary/elementary teacher education programmes. Thus, the research base of IBSE in secondary science teacher education is limited.

Finally, in the reviewed material, only a few studies focused on PSTs' development over time. Most of the included studies were based on a relatively limited intervention over a few weeks or a single course, and the majority of these studies reported a positive development of the PSTs' competence. A few studies have investigated the learning effect over time and the effect of the studied interventions compared to other learning and teaching approaches.

IBSE in teacher education in terms of the two-dimensional framework

In this review, we propose a framework for categorising IBSE in teacher education, by combining the distinction between IBL and IBT with a categorisation into cognitive domains. Our framework builds on and extends previous work (Anderson, 2002; Duschl, 2008; Furtak et al., 2012) and makes both theoretical and methodological contributions. In our framework, the previous categorisations with four domains (*cognitive, procedural, epistemic*, and *social*) are extended with two domains: The *pedagogical domain* is specific to teacher education and concerns general aspects of learning how to implement IBSE in a classroom. The *affective domain* highlights how attitudes, motivation, self-efficacy, and other affective factors may shape the outcome of IBSE for PSTs. Interestingly, two recent articles, Nhlengethwa et al. (2020) and Nhlengethwa et al. (2021), used the domains of Duschl (2008) and Furtak et al. (2012) as a tool for analysing empirical data from teacher education. This demonstrates the applicability of the framework for getting an overview of PSTs' experience with IBSE.

Here, we discuss the main findings from the reviewed articles, structured according to our two-dimensional framework. 49 % of the reviewed articles were categorised as IBL. These studies reported on IBL as a method for learning science in general, but they discussed little about how PSTs develop the skill set necessary to implement IBT successfully in science classrooms. A possible explanation for the high number of IBL articles may be that some of the articles did not have teacher education as their main focus but used PSTs (perhaps a conveniently available group) to investigate IBL in higher education generally. The remaining 51 % of the articles addressed IBT by focusing on preparing PSTs for performing inquiry as part of the science teaching profession. Many of the articles emphasised the importance of letting PSTs experience IBL in the student role and of preparing them for conducting IBT in the teacher role. However, only a few articles described a full progression from conducting IBL in the student role to that in the teacher role.

In terms of the six cognitive domains in our analytical framework, only a few articles concerned the *epistemic domain*, which has to do with how scientific knowledge is developed. As IBSE itself mimics central aspects of the scientific research process, it is striking that little research appears to have been conducted on how this cognitive domain is treated in the context of IBSE in teacher education. The epistemic domain is also closely related to NOS, a central aim of science education worldwide (Lederman & Lederman, 2014). Of the few reviewed papers in this domain, some observed PSTs' insufficient understanding of the nature of scientific work and recommended targeted teaching and learning activities that allow PSTs to develop the level of epistemic reflection necessary to successfully implement IBT in the classroom (e.g. Lotter et al., 2009). This is consistent with Sandoval (2005), who pointed out that it is important for learners to connect their own investigations with the way real scientists work and generate knowledge. Work in the epistemic domain also enables learners to develop an interest in scientific inquiry (Sandoval, 2005; Van Uum et al., 2016).

The *procedural domain* is better represented in our reviewed material. Procedural skills were seen as both a prerequisite and a learning outcome in IBSE activities in teacher education. Explicit instruction was recommended on how to perform the various practices involved in an inquiry process, such as asking 'researchable' questions and formulating and testing hypotheses (e.g. Cruz-Guzmán et al., 2017). This is in agreement with Gyllenpalm and Wickman (2011a, Gyllenpalm and Wickman, 2011b), who suggested that PSTs should develop their understanding of concepts such as 'hypothesis' and 'experiment'.

Similar to the procedural domain, PSTs' competence in the *conceptual domain* was seen as a prerequisite and an aim for the IBL and IBT approaches described in the articles. Several articles remarked on the insufficient content knowledge that inhibits PSTs' IBL and IBT competence. Conversely, several articles have reported favourable outcomes of IBL and IBT processes in terms of increased conceptual understanding. The approach of allowing PSTs to critique, adapt and design IBT resources for classrooms was recommended to increase PSTs' level of reflection in the procedural, conceptual and other domains.

The *social domain* was sparsely represented in the reviewed material, but the few articles that were examined pointed to ways of developing PSTs' argumentation skills and their skills in guiding inquiry dialogue in the classroom. One article used argumentation-based inquiry as the context (Ecevit & Kaptan, 2022), but the research is not related to argumentation or other parts of the social domain. Again, we find the scarcity of research in the social domain of IBSE alarming given the central role of communication and argumentation in the inquiry process. Furtak et al. (2012) pointed out the importance of IBSE allowing pupils to develop and justify explanations and discuss these in class. Furthermore, the social domain is explicitly a part of the definition of IBSE given by Crawford (2014): ' . . . communicating findings in the pursuit of deepening their understanding by using logic and evidence about the natural world' (p. 515). This underlines the central role played by argumentation in science education, as emphasised by Osborne (2010) and Simon et al. (2006). Engaging learners in the social domain is also essential for promoting 21st-century skills and deeper learning in science (Haug & Mork, 2021). Thus, we would have expected to find more research on how to develop PSTs' competence in promoting pupils' argumentation and sensemaking in IBSE processes. One of the few articles in the social domain (Ozdem et al., 2013) showed the importance of allowing PSTs to practice their own argumentation skills to be able to support pupils in argumentation in inquiry processes.

As expected, the *pedagogical domain* was well represented among the IBT articles in our sample. Many articles emphasised that teacher education must educate candidates in orchestrating the many aspects of IBSE in the classroom, and several articles commented on the challenges met by PSTs during school placement, such as managing time and meeting curriculum and assessment requirements. A number of articles considered reflection activities important for PSTs to develop their competence in orchestrating IBSE in the classroom. Specifically, Duncan et al. (2010) recommended that engagement in instructional design could increase PSTs' ability to evaluate and revise instructional material and that this could be a suitable model for building PSTs' skills in designing IBT.

The *affective domain* was added to our analytical framework based on the large number of articles addressing the issues of attitudes, self-efficacy, and identity related to IBSE in science teacher education. This is a reminder of the central role that these affective variables play if PSTs are to take ownership of the inquiry approach and apply it meaningfully, both as learners (IBL) and as teachers (IBT). PSTs need to have mastery experiences and to develop an identity as 'inquiry-based teachers' if they are to practice this approach in school cultures that may in some cases favour more traditional teaching and learning approaches. The reviewed research shows that a range of background factors shape PSTs' affective responses to IBSE interventions and that more research is needed to map out these complex relationships and provide examples of how PSTs' IBSE skills can be developed, given the differences in backgrounds and local conditions.

Some articles, which were categorised in *other*, focused on how IBSE relates to the use of technology or to development of learners' critical and creative thinking skills. Technology-enhanced IBL approaches may support PSTs learning under some conditions (Arabacioglu & Unver, 2016), but others argued that PSTs may have insufficient prior teaching and learning experiences for using technology effectively in IBSE (Schmidt & Fulton, 2017). IBSE may also support PSTs' critical and creative thinking skills, which are again. essential for promoting 21st-century skills deeper learning (Haug & Mork, 2021).

Table 4. A summary of trends and tendencies within IBSE and domains.

	Beneficial outcomes of IBSE	Challenges with IBSE	Areas for further research and development
Epistemic domain: Learning about science as inquiry and the nature of science (NOS)	• IBL may contribute to developing PSTs' understanding of epistemic aspects, particularly when NOS is given explicit attention. • It is possible to develop PSTs' level of epistemic reflection through targeted teaching and learning experiences with interplay between theoretical input, classroom teaching experience and guided reflection.	• PSTs struggle to understand NOS when working with IBL. • PSTs struggle with including NOS perspectives in IBT. • Many PSTs enter teacher education with poor preparation in the epistemic aspects of inquiry and if left unattended, they leave with insufficient understanding as well.	• The epistemic domain is insufficiently covered and need increased attention. Research and development should aim to identify fruitful ways for PSTs to develop their understanding of epistemic aspects of IBSE in the student role as well as in the teacher role.
Procedural domain: Developing learners' inquiry skills	• PSTs can increase their inquiry skills when working with IBL, but they need explicit instruction about procedural aspects and sufficient content knowledge to enter meaningfully into the different practices involved in IBSE. • Approaches where PSTs progress from engaging in IBL in the role of students to planning and conducting IBT may support PSTs' procedural skills and prepare them for thoughtful implementation of IBT. • Critiquing existing IBT resources, adapting such resources and finally designing their own IBT resources for use in the classroom may improve PSTs' procedural skills.	• PSTs are insufficiently educated in the different stages of inquiry processes. • PSTs have challenges with several scientific practices, such as posing researchable questions, formulating hypotheses, and choosing a strategy for investigation. • PSTs struggle with the transition from IBL to IBT. They have positive views of IBL, but they experience that it is difficult to implement inquiry procedures it in the classroom.	• In teacher education, PSTs need to experience IBL in the student role with sufficient scaffolding and with explicit attention to the practices of IBSE. • There is still a relative scarcity of research papers reporting on comprehensive learning progressions for where PSTs build up their procedural skills through IBL and well as IBT experiences.
Conceptual domain: Using inquiry to learn science content knowledge	• PSTs can gain increased subject matter understanding through working with IBL.	• Insufficient content knowledge may inhibit PSTs' ability to conduct IBT with pupils.	• Research is needed on how IBL compares with other instructional approaches to develop PSTs' content knowledge.

(*Continued*)

Table 4. (Continued).

	Beneficial outcomes of IBSE	Challenges with IBSE	Areas for further research and development
Social domain: Constructing science knowledge and arguing from evidence in a social process while working with inquiry	• IBSE with a distinct focus on argumentation can support and promote PSTs' argumentation skills.	• PSTs struggle with constructing scientific arguments of high quality. • PSTs needs scaffolding in how to orchestrate interactive classroom discussions when carrying out IBT.	• There is no research on communication and collaboration among the IBL-studies and no research on argumentation among the IBT-studies. Published research gives limited attention to, and examples of, how to work with the social domain in IBSE in teacher education. Research and development are needed to identify fruitful approaches. • Best-practice examples are needed of how to develop PSTs' ability to scaffold interactive classroom discussions in IBT.
Pedagogical domain: Teacher and student roles during IBSE; general aspects of teaching/learning through IBSE; PSTs' views on IBSE as a pedagogical approach	• There are many research examples of how PSTs learn and experience how to implement IBSE as future teachers. • Different procedures, such as microteaching, co-learning, co-teaching, are reported to support PSTs in developing IBT-skills. • Reflection activities are important to develop PSTs' competence in orchestrating IBSE in the classroom.	• PSTs struggle to transfer their experiences of doing science (IBL) to actively using these experiences in IBT with pupils. • The weak connection that some PSTs experience between the campus-based parts of teacher education and classroom practice is a challenge for developing their IBT skills.	• Teacher educators need to explicitly model good IBSE for PSTs as part of teacher education. • PSTs need experience with and support in working with inquiry during their school placement. The teachers they meet in school placement need to support an inquiry-based approach to science teaching.
Affective domain: Attitudes, self-efficacy, identity, and beliefs related to IBSE	• IBL as well as IBT experiences may support PSTs' development of self-efficacy and positive attitudes to both IBSE and science teaching in general.	• The affective outcomes are shaped by a range of background factors and previous experiences, so that different subgroups of students display different affective responses to IBSE.	• The role of background variables such as previous experiences in shaping PSTs' affective response to IBSE remain to be explored in more detail. • Teacher education needs to pay attention to supporting PSTs' self-efficacy and identity development related to IBSE.
Other • Use of technology in IBSE • Effect of IBSE on PSTs' metacognition skills, creative or critical thinking dispositions	• Technology-enhanced IBL approaches, such as wikis or "mobile learning", may support PSTs' learning under some conditions. • IBL may support PSTs' critical and creative thinking skills. • PSTs are willing to include technology in IBT.	• Many PSTs may have insufficient prior teaching and learning experiences for using technology effectively in IBSE.	• There is limited research on how IBSE relates to PSTs' use of technology and to their metacognitive, critical, and creative thinking skills.

However, the reviewed studies displayed mixed results, which indicates that more research is needed to identify fruitful ways for integrating such skills with IBSE in teacher education.The domains were closely related to each other, and many of the reviewed articles discussed several domains and the interplay between them. According to Van Uum et al. (2016), an IBSE activity can include several domains, and learners often need to shift between the different domains during the different stages of the activity. Based on their meta-study, Furtak et al. (2012) argued that IBSE has a positive effect on pupils' learning but has a larger effect when the epistemic, procedural and social domains are combined.

To summarise IBSE in teacher education, Table 4 provides a summary of the beneficial outcomes, challenges and areas for further research and development within IBSE that we have pointed to in this review.

Recommendations for integrating IBSE with comprehensive science teacher education

Based on our analysis and discussion of how IBSE is implemented in teacher education, we present some recommendations for integrating IBSE with comprehensive science teacher education. Overall, and in line with Hamed et al. (2020), we recommend that teacher education programmes should have a longitudinal plan for integrating IBSE through the courses. The implementation of IBSE is complex, and it is difficult to cover all dimensions through a single course. When IBSE is implemented throughout the programme, PSTs can gain experience in learning science concepts and processes through IBSE and in teaching through inquiry. Specifically, we recommend increasing the focus on the transition between IBL and IBT, as PSTs tend to see few connections between these dimensions (Bansal, 2021; Gunckel & Wood, 2016). In our study, we found relatively few examples of PSTs progressing from IBL to IBT, although our review suggests that this would be fruitful for preparing PSTs for quality inquiry teaching (e.g. Baxter et al., 2004; Haefner & Zembal-Saul, 2004; Varma et al., 2009).

To help with the transition from IBL to IBT, teacher educators should use explicit modelling (Lunenberg et al., 2007) to provide and discuss examples of how to orchestrate IBSE in the classroom. Given that research points to teacher guidance as vital for pupils' learning outcomes of IBSE (Aditomo & Klieme, 2020; Zhang & Cobern, 2020), teacher educators can model effective strategies for scaffolding IBSE, including suitable communication patterns and ways of encouraging pupils' reasoning. Furthermore, we recommend including reflection sequences after IBL activities, which is considered by Baxter et al. (2004) as important in the transition from IBL to IBT. Based on the reviewed studies we also recommend that PSTs should first conduct inquiry in the role as learners and then reflect on, critique, and modify IBT resources, preferably scaffolded by a teacher educator or other mentors. In this way, they can obtain the skills and confidence to design and conduct inquiry-based activities themselves.

As part of the longitudinal plan for IBSE, we also suggest focusing on PSTs' school placement. Several studies have reported on the tension between the more theoretical, campus-based parts of teacher education, which often promote IBSE as an ideal, and the reality PSTs face in the classroom during their school placement, in which more traditional teaching and learning approaches and a range of practical constraints can restrict their success in implementing IBSE (e.g. Britner & Finson, 2005; Fazio et al., 2010; Yoon et al., 2012). This can be linked to 1999) description of the challenges of moving from pursuing 'knowledge-*for*-practice' in the campus-based, theoretical parts of education to 'knowledge-*in*-practice' in school placement. Among the suggested ways to relieve this tension are co-learning (Gunckel & Wood, 2016) and co-teaching (Eick & Dias, 2005; McCullagh & Doherty, 2021) approaches and promoting coherence between the different parts of the teacher education programme. Greca (2016) recommended using 'the third discursive space' to help PSTs integrate theoretical knowledge gained in campus-based settings with observations and experiences from classroom practice. Moreover, different reflection tasks have been recommended in many of the reviewed articles (e.g. Lotter et al., 2009; Zhou & Xu, 2017). These reflection tasks enable PSTs to develop individually as an 'inquiry-based teacher' and to make the connection between the campus-based and the school practice parts of their education through group discussions or co-reflection tasks involving mentor teachers.

Finally, based on the large number of studies addressing PSTs' attitudes, beliefs, and self-efficacy in IBSE (e.g. Del Greco et al., 2018; Duran et al., 2004), we recommend focusing on the affective domain, for instance by providing PSTs with mastery experiences in IBSE.

Suggestions for further research

Based on this review, we suggest four areas for further research. First, only a few studies highlighted the transition from IBL to IBT, and these studies revealed that PSTs struggle to transfer their own experiences from 'doing' science to actively using these experiences in designing teaching and learning activities. Therefore, further research is needed on this transition and how teacher educators can scaffold PSTs in the transition.

Second, we found a lack of studies on how to educate PSTs to include the epistemic and social domains more explicitly in their IBT. This is particularly important given the central role of NOS and argumentation skills in science education (Lederman & Lederman, 2014). Therefore, future research should focus on the aspects of IBSE that are crucial to pupils' learning, notably developing PSTs' skills in scaffolding and guiding pupils in the inquiry process (Aditomo & Klieme, 2020; Hmelo-Silver et al., 2007), especially in these two domains.

Third, many of the reviewed studies were conducted within a limited part of the teacher education programme, such as a science methods course. In these articles, we did not get much information about the IBSE focus (or lack of thereof) in the courses that the PSTs attended before or after this course. The studies provided more of a snapshot of various single methods courses. Therefore, there seems to be a need for larger-scale and longitudinal studies addressing the role of IBSE through an entire teacher education programme rather than just one single course. Also, there is a lack of focus on IBSE in teacher education programmes aiming at teaching on the secondary level.

Finally, broader geographical and cultural variation is needed in published research of how IBSE develops in teacher education in different contexts.

Limitations of the study

The limitations of this review are generally related to the search and the inclusion and exclusion criteria applied, as these affect the width and depth of the systematic review (Gough et al., 2017). To ensure the width and depth within science education research, the search was conducted in three databases: Web of Science, ERIC, and Education Source, the two latter via EBSCOhost. These databases represent both subject specific and educational databases, as suggested by Gough et al. (2017). To make sure that relevant studies were included, a manual search in four journals was conducted. The scope for these journals is relevant to our aim and to our inclusion and exclusion criteria.

Furthermore, this review used three search strings, related to IBSE, teacher education and science respectively. The search was conducted in titles, keywords, and abstracts. A limitation related to the IBSE search string is that IBSE is described and categorised in various ways in the literature. For example, the word 'enquiry' was not included. Traditionally, 'enquire' in the United Kingdom means 'ask', while 'inquire' is used for formal investigations. In the United Kingdom, the two words are used interchangeably, but in the United States, 'inquire' is the preferred spelling in all uses. Including the term 'enquiry' in the keywords could have led to additional studies. Moreover, the present study was limited to research using 'inquiry' as a term and did not include studies (only) using the term 'scientific practices'. In this study, we focus on IBSE, mainly because many influential research and curriculum documents have used this term (Crawford, 2014; European Commission Directorate-General for Research Innovation, 2015; Rocard et al., 2007). This places our review in the 'inquiry' tradition, overlooking relevant studies that use 'scientific practices' instead of 'inquiry'. In terms of the third search string related to science, we specifically included the disciplines of biology, chemistry, and physics in addition to from science. Adding more specific science disciplines as search phrases could have resulted in a few additional articles.

Regarding the limitations related to the inclusion and exclusion criteria, the sample of reviewed studies was drawn from peer-reviewed journals to ensure quality. Focusing on this type of publication may have limited the scope of the perspectives on IBSE in science teacher education. Including conference papers, reports, dissertations, books, and book chapters could have extended the material available for analysis, but it would also have made it more demanding to obtain an overview of and go into detail on the included material. This argument is also related to further decisions made about including studies published within the last 22 years and those published in the English language. The language criterion may have contributed to the Western-dominated impression of how IBSE is implemented. For example, there may exist considerable research bases related to inquiry in German and Spanish, perhaps also in various Asian and African languages. Pursuing such literature was not possible with the resources available for the present study.

As this review focused on the use of IBL and IBT, as well as the cognitive domains, other aspects of the examined articles were put in the background, such as the methods employed and the contexts in which the studies were conducted. Certainly, a review with a different analytical framework would have foregrounded other aspects of the studies than the ones highlighted through our chosen analytical framework.

Conclusion

This study presents a systematic review of 142 empirical studies on IBSE in teacher education from 2000 to 2022. The included studies highlighted several favourable outcomes of IBSE, such as increased science understanding and teaching competence and improved attitudes or self-efficacy. Challenges were also reported, such as implementing IBSE if PSTs are insufficiently educated in the different stages of an inquiry process and implementing IBSE in school placement after having learned about it in campus-based courses.

This review makes theoretical and methodological contributions by proposing a two-dimensional framework for categorising IBSE in teacher education. The framework combines the distinction between IBL and IBT, that is, whether the PSTs worked with inquiry in the role of a learner or in the role of a teacher, with six different domains: epistemic, procedural, conceptual, social, pedagogical, and affective. The majority of the articles describe the use of IBSE either for PSTs to learn science concepts and processes (i.e. IBL) or for them to teach through inquiry (i.e. IBT), whereas fewer studies focused on the transition between IBL and IBT. In terms of the distribution of the articles into the domains, the procedural, conceptual, pedagogical, and affective domains dominate; only a few articles focus on the epistemic or social domains. Overall, the two-dimensional framework is useful for highlighting the weakly represented areas in the research on IBSE in teacher education, and it can also be used as a reflection tool for teacher educators to ensure that all domains are covered during the PSTs' time in teacher education. The framework, together with the empirically based recommendations described in this article, can help teacher educators provide rich and nuanced inquiry experiences for their PSTs, empowering them in their future science teaching.

Acknowledgments

A version of this article was presented at The Nordic Research Symposium on Science Education (NFSUN), May 2021, Aarhus. Denmark.

We thank librarians at our university library for supporting and guiding our search strategies.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

Funding was provided by the Research Council of Norway, grant no 300672

Notes on contributors

Tonje Tomine Seland Strat is a Ph.D. candidate in science education at the Department of Primary and Secondary Teacher Education, OsloMet – Oslo Metropolitan University. Her research concerns science teacher education and pre-service teachers' learning in higher education and at present, she is involved in several studies focusing on inquiry-based science education and research-based teacher education.

Ellen Karoline Henriksen is a professor in science/physics education at the Department of Primary and Secondary Teacher Education, OsloMet – Oslo Metropolitan University and at the Department of Physics, University of Oslo. Her research interests include teaching and learning physics in school and inquiry-based science education as well as physics teacher and science teacher competence.

Kirsti Marie Jegstad is an associate professor in science education at Department of Primary and Secondary Teacher Education, OsloMet – Oslo Metropolitan University. Her research interests include chemistry education, inquiry-based science education, critical thinking, education for sustainable development and research-based teacher education.

ORCID

Tonje Tomine Seland Strat http://orcid.org/0000-0001-6778-7539

References

Abell, S., Appleton, K., & Hanuscin, D. (2010). *Designing and teaching the elementary science methods course*. Routledge. https://doi.org/10.4324/9780203859131

Abrams, E., Southerland, S., & Evans, C. (2007). Inquiry in the classroom: Identifying necessary components of au useful definition. In E. Abrams, S. Southerland, & P. Silva (Eds.), *Inquiry in the classroom: Realities and opportunities* (pp. pp. 11–42). Age of Information Press.

Acarli, D. S., & Dervişoğlu, S. (2021). Effect of inquiry-based biology laboratory applications on scientific process skills, attitude, self-efficacy and self-confidence. *MIER Journal of Educational Studies, Trends and Practices*, 15–29. https://doi.org/10.52634/mier/2021/v11/i1/1751

Aditomo, A., & Klieme, E. (2020). Forms of inquiry-based science instruction and their relations with learning outcomes: Evidence from high and low-performing education systems. *International Journal of Science Education*, *42*(4), 504–525. https://doi.org/10.1080/09500693.2020.1716093

Adler, I., Schwartz, L., Madjar, N., & Zion, M. (2018). Reading between the lines: The effect of contextual factors on student motivation throughout an open inquiry process. *Science Education*, *102*(4), 820–855. https://doi.org/10.1002/sce.21445

Aidoo, B., Anthony-Krueger, C., Gyampoh, A. O. G., Tsyawo, J., & Quansah, F. (2022). A mixed-method approach to investigate the effect of flipped inquiry-based learning on chemistry students learning. *European Journal of Science and Mathematics Education*, *10*(4), 507–518. https://doi.org/10.30935/scimath/12339

Akgul, E. M. (2006). Teaching science in an inquiry-based learning environment: What it means for pre-service elementary science teachers. *EURASIA Journal of Mathematics, Science & Technology Education*, *2*(1), 71–81. https://doi.org/10.12973/ejmste/75439

Amos, R., & Levinson, R. (2019). Socio-scientific inquiry-based learning: An approach for engaging with the 2030 sustainable development goals through school science. *International Journal of Development Education & Global Learning*, *11*(1), 29–49. https://doi.org/10.18546/IJDEGL.11.1.03

Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education*, *13*(1), 1–12. https://doi.org/10.1023/A:1015171124982

Arabacioglu, S., & Unver, A. O. (2016). Supporting inquiry based laboratory practices with mobile learning to enhance students' process skills in science education. *Journal of Baltic Science Education*, *15*(2), 216–231. https://doi.org/10.33225/jbse/16.15.216

Arsal, Z. (2017). The impact of inquiry-based learning on the critical thinking dispositions of pre-service science teachers. *International Journal of Science Education*, *39*(10), 1326–1338. https://doi.org/10.1080/09500693.2017.1329564

Asy'ari, M., Ikhsan, M. & Muhali, M. (2019). The effectiveness of inquiry learning model in improving prospective teachers' metacognition knowledge and metacognition awareness. *International Journal of Instruction*, *12*(2), 455–470. https://doi.org/10.29333/iji.2019.12229a
Avery, L. M., & Meyer, D. Z. (2012). Teaching science as science is practiced: Opportunities and limits for enhancing preservice elementary teachers' self-efficacy for science and science teaching. *School Science & Mathematics*, *112*(7), 395–409. https://doi.org/10.1111/j.1949-8594.2012.00159.x
Aydin, M. (2019). Investigating pre-service science teachers mobile augmented reality integration into worksheets. *Journal of Biological Education*, *55*(3), 276–292. https://doi.org/10.1080/00219266.2019.1682639
Banchi, H., & Bell, R. (2008). The many levels of inquiry. *Science and Children*, *46*(2), 26–29. https://doi.org/10.2505/3/sc08_046_02
Bansal, G. (2021). Indian pre-service teachers' conceptualisations and enactment of inquiry-based science education. *Education 3-13*, *49*(3), 275–287. https://doi.org/10.1080/03004279.2020.1854957
Baxter, B. K., Jenkins, C. C., Southerland, S. A., & Wilson, P. (2004). Using a multilevel assessment scheme in reforming science methods courses. *Journal of Science Teacher Education*, *15*(3), 211–232. https://doi.org/10.1023/B:JSTE.0000047084.51834.a3
Bhattacharyya, S., Volk, T., & Lumpe, A. (2009). The influence of an extensive inquiry-based field experience on pre-service elementary student teachers' science teaching beliefs. *Journal of Science Teacher Education*, *20*(3), 199–218. https://doi.org/10.1007/s10972-009-9129-8
Biggers, M., & Forbes, C. T. (2012). Balancing teacher and student roles in elementary classrooms: Preservice elementary teachers' learning about the inquiry continuum. *International Journal of Science Education*, *34*(14), 2205–2229. https://doi.org/10.1080/09500693.2012.694146
Binns, I. C., & Popp, S. (2013). Learning to teach science through inquiry: Experiences of preservice teachers. *Electronic Journal of Science Education*, *17*(1), 1–24.
Bjønness, B., & Kolstø, S. D. (2015). Scaffolding open inquiry: How a teacher provides students with structure and space. *NorDina, Nordic Studies in Science Education*, *11*(3), 223–237. https://doi.org/10.5617/nordina.878
Britner, S. L., & Finson, K. D. (2005). Preservice teachers' reflections on their growth in an inquiry-oriented science pedagogy course. *Journal of Elementary Science Education*, *17*(1), 39–54. https://doi.org/10.1007/BF03174672
Bruckermann, T., Aschermann, E., Bresges, A., & Schlüter, K. (2017). Metacognitive and multimedia support of experiments in inquiry learning for science teacher preparation. *International Journal of Science Education*, *39*(6), 701–722. https://doi.org/10.1080/09500693.2017.1301691
Bryant, R. (2006). Assessment results following inquiry and traditional physics laboratory activities. *Journal of College Science Teaching*, *35*(7), 56–61.
Buyruk, A. A., & Bekiroglu, F. O. (2018). Comparison of pre-service physics teachers' conceptual understanding of dynamics in model-based scientific inquiry and scientific inquiry environments. *Journal of Education in Science, Environment and Health*, *4*(1), 93–109.
Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins, effectiveness, and applications*. BSCS science learning. http://www.fremonths.org/ourpages/auto/2008/5/11/1210522036057/bscs5efullreport2006.pdf
Cartwright, T., Smith, S., & Hallar, B. (2014). Confronting barriers to teaching elementary science: After-school science teaching experiences for preservice teachers. *Teacher Education & Practice*, *27*(2/3), 464–487.
Cian, H., Dsouza, N., Lyons, R., & Cook, M. (2017). Influences on the development of inquiry-based practices among preservice teachers. *Journal of Science Teacher Education*, *28*(2), 186–204. https://doi.org/10.1080/1046560X.2016.1277832
Cochran-Smith, M., & Lytle, S. L. (1999). Chapter 8: Relationships of knowledge and practice: Teacher learning in communities. *Review of Research in Education*, *24*(1), 249–305. https://doi.org/10.3102/0091732X024001249
Crawford, B. A. (2014). From inquiry to scientific practices in the science classroom. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education, volume II* (pp. 515–541). Routledge.

Crawford, B. A., & Capps, D. K. (2018). Teacher cognition of engaging children in scientific practices. In Y. J. Dori, Z. R. Mevarech, & D. R. Baker (Eds.), *Cognition, metacognition, and culture in STEM education* (pp. 9–32). Springer.

Crawford, B. A., Zembal-Saul, C., Munford, D., & Friedrichsen, P. (2005). Confronting prospective teachers' ideas of evolution and scientific inquiry using technology and inquiry-based tasks. *Journal of Research in Science Teaching*, *42*(6), 613–637. https://doi.org/10.1002/tea.20070

Cruz-Guzmán, M., García-Carmona, A., & Criado, A. M. (2017). An analysis of the questions proposed by elementary pre-service teachers when designing experimental activities as inquiry. *International Journal of Science Education*, *39*(13), 1755–1774. https://doi.org/10.1080/09500693.2017.1351649

Cruz-Guzmán, M., García-Carmona, A., & Criado, A. M. (2020). Proposing questions for scientific inquiry and the selection of science content in initial elementary education teacher training. *Research in Science Education*, *50*(5), 1689–1711. https://doi.org/10.1007/s11165-018-9749-0

Del Greco, R., Bernadowski, C., & Parker, S. (2018). Using illustrations to depict preservice science teachers' self-efficacy: A case study. *International Journal of Instruction*, *11*(2), 75–88. https://doi.org/10.12973/iji.2018.1126a

Dewey, J. (1938). The school and society. In M. Dworkin (Ed.), *Dewey on education*. (pp. 33–90). Teachers College Press .

Dobber, M., Zwart, R., Tanis, M., & van Oers, B. (2017). Literature review: The role of the teacher in inquiry-based education. *Educational Research Review*, *22*, 194–214. https://doi.org/10.1016/j.edurev.2017.09.002

Docherty-Skippen, S. M., Karrow, D., & Ahmed, G. (2020). Doing science: Pre-service teachers' attitudes and confidence teaching elementary science and technology. *Brock Education: A Journal of Educational Research and Practice*, *29*(1), 25–35. https://doi.org/10.26522/brocked.v29i1.768

Duncan, R. G., Pilitsis, V., & Piegaro, M. (2010). Development of preservice teachers' ability to critique and adapt inquiry-based instructional materials. *Journal of Science Teacher Education*, *21*(1), 81–102. https://doi.org/10.1007/s10972-009-9153-8

Duran, L. B., McArthur, J., & Van Hook, S. (2004). Undergraduate students' perceptions of an inquiry-based physics course. *Journal of Science Teacher Education*, *15*(2), 155–171. https://doi.org/10.1023/B:JSTE.0000044865.64149.62

Duschl, R. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of Research in Education*, *32*(1), 268–291. https://doi.org/10.3102/0091732X07309371

Ecevit, T., & Kaptan, F. (2022). Argümantasyona Dayalı Araştırma-Sorgulamaya Uygulamalarının Fen Öğretmen Adayı Eğitimindeki Etkililiği. *Kuramsal Eğitimbilim*, *15*(4), 721–757. https://doi.org/10.30831/akukeg.1070893

Eick, C. J. (2000). Inquiry, nature of science, and evolution: The need for a more complex pedagogical content knowledge in science teaching. *Electronic Journal of Science Education*, *4*(3), 1–16.

Eick, C. J., & Dias, M. (2005). Building the authority of experience in communities of practice: The development of preservice teachers' practical knowledge through coteaching in inquiry classrooms. *Science Education*, *89*(3), 470–491. https://doi.org/10.1002/sce.20036

Eick, C. J., & Reed, C. J. (2002). What makes an inquiry-oriented science teacher? The influence of learning histories on teacher role identity and practice. *Science Education*, *86*(3), 401–416. https://doi.org/10.1002/sce.10020

Enugu, R., & Hokayem, H. (2017). Challenges pre-service teachers face when implementing a 5E inquiry model of instruction. *European Journal of Science and Mathematics Education*, *5*(2), 178–209. https://doi.org/10.30935/scimath/9506

European Commission Directorate-General for Research Innovation. (2015). *Science education for responsible citizenship: Report to the European Commission of the expert group on science education*. Publications Office. https://doi.org/10.2777/12626

Fazio, X., Melville, W., & Bartley, A. (2010). The problematic nature of the practicum: A key determinant of pre-service teachers' emerging inquiry-based science practices. *Journal of Science Teacher Education*, *21*(6), 665–681. https://doi.org/10.1007/s10972-010-9209-9

Feyzioglu, B. (2019). Examination of laboratory perceptions of pre-service science teachers with different goal orientations on inquiry-based analytical chemistry courses: A case study. *International Journal of Education in Mathematics, Science and Technology*, *7*(3), 281–310.

Forbes, C. (2013). Curriculum-dependent and curriculum-independent factors in preservice elementary teachers' adaptation of science curriculum materials for inquiry-based science. *Journal of Science Teacher Education*, *24*(1), 179–197. https://doi.org/10.1007/s10972-011-9245-0

Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching: A meta-analysis. *Review of Educational Research*, *82*(3), 300–329. https://doi.org/10.3102/0034654312457206

García-Carmona, A. (2017). Pre-service primary science teachers' abilities for solving a measurement problem through inquiry. *International Journal of Science & Mathematics Education*, *17*(1), 1–21. https://doi.org/10.1007/s10763-017-9858-7

García-Carmona, A., Criado, A., & Cruz-Guzmán, M. (2016). Primary pre-service teachers' skills in planning a guided scientific inquiry. *Research in Science Education*, *47*(5), 989–1010. https://doi.org/10.1007/s11165-016-9536-8

Gencer, S., & Ekici, F. (2022). Preservice chemistry teachers' understanding of surface tension through guided-inquiry. *Journal of Chemical Education*, *99*(12), 3946–3953. https://doi.org/10.1021/acs.jchemed.2c00330

Gericke, N., Högström, P., & Wallin, J. (2022). A systematic review of research on laboratory work in secondary school. *Studies in Science Education*, 1–41. https://doi.org/10.1080/03057267.2022.2090125

Gilbert, A. (2009). Utilizing science philosophy statements to facilitate K-3 teacher candidates' development of inquiry-based science practice. *Early Childhood Education Journal*, *36*(5), 431–438. https://doi.org/10.1007/s10643-009-0302-7

Glackin, M., & Harrison, C. (2018). Budding biology teachers: What have botanical gardens got to offer inquiry learning. *Journal of Biological Education*, *52*(3), 283–293. https://doi.org/10.1080/00219266.2017.1357648

Goldston, M., Dantzler, J., Day, J., & Webb, B. (2013). A psychometric approach to the development of a 5E lesson plan scoring instrument for inquiry-based teaching. *Journal of Science Teacher Education*, *24*(3), 527–551. https://doi.org/10.1007/s10972-012-9327-7

Gough, D. A., Oliver, S., & Thomas, J. (2017). *An introduction to systematic reviews* (2 ed.). SAGE.

Grant, M. J., & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal*, *26*(2), 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Graves, C., & Rutherford, S. (2012). Writing a scientific research ("testable") question: The first step in using online data sets for guided inquiry assignments. *Journal of College Science Teaching*, *41*(4), 46–51.

Greca, I. M. (2016). Supporting pre-service elementary teachers in their understanding of inquiry teaching through the construction of a third discursive space. *International Journal of Science Education*, *38*(5), 791–813. https://doi.org/10.1080/09500693.2016.1165892

Gunckel, K. L., & Wood, M. B. (2016). The principle-practical discourse edge: Elementary preservice and mentor teachers working together on colearning tasks. *Science Education*, *100*(1), 96–121. https://doi.org/10.1002/sce.21187

Gurel, C., & Suzuk, E. (2017). Pre-service physics teachers' argumentation in a model rocketry physics experience. *Educational Sciences: Theory & Practice*, *17*(1), 83–104. https://doi.org/10.12738/estp.2017.1.0042

Gyllenpalm, J., & Wickman, P. O. (2011a). "Experiments" and the inquiry emphasis conflation in science teacher education. *Science Education*, *95*(5), 908–926. https://doi.org/10.1002/sce.20446

Gyllenpalm, J., & Wickman, P. O. (2011b). The uses of the term hypothesis and the inquiry emphasis conflation in science teacher education. *International Journal of Science Education*, *33*(14), 1993–2015. https://doi.org/10.1080/09500693.2010.538938

Hacıeminoğlu, E., Yıldız, N. G., & Şeker, R. (2022). Factors related to cognitive reasoning of pre-service teachers' science process skills: Role of experiments at home on meaningful learning. *Sustainability*, *14*(13), 7703. https://doi.org/10.3390/su14137703

Haefner, L. A., & Zembal-Saul, C. (2004). Learning by doing? Prospective elementary teachers' developing understandings of scientific inquiry and science teaching and learning. *International Journal of Science Education*, *26*(13), 1653–1674. https://doi.org/10.1080/0950069042000230709

Hakverdi-Can, M., & Sönmez, D. (2012). Learning how to design a technology supported inquiry-based learning environment. *Science Education International*, *23*(4), 338–352.

Hamed, S., Ezquerra, Á., Porlán, R., & Rivero, A. (2020). Exploring pre-service primary teachers' progression towards inquiry-based science learning. *Educational Research*, *62*(3), 357–374. https://doi.org/10.1080/00131881.2020.1780624

Haug, B. S., & Mork, S. M. (2021). Taking 21st century skills from vision to classroom: What teachers highlight as supportive professional development in the light of new demands from educational reforms. *Teaching and Teacher Education*, *100*, 103286. https://doi.org/10.1016/j.tate.2021.103286

Hayes, M. T. (2002). Elementary preservice teachers' struggles to define inquiry-based science teaching. *Journal of Science Teacher Education*, *13*(2), 147–165. https://doi.org/10.1023/A:1015169731478

Herranen, J., Kousa, P., Fooladi, E., & Aksela, M. (2019). Inquiry as a context-based practice – a case study of pre-service teachers' beliefs and implementation of inquiry in context-based science teaching. *International Journal of Science Education*, *41*(14), 1977–1998. https://doi.org/10.1080/09500693.2019.1655679

Herron, M. D. (1971). The nature of scientific enquiry. *The School Review*, *79*(2), 171–212. https://doi.org/10.1086/442968

Hiltunen, M., Kärkkäinen, S., & Keinonen, T. (2021). Identifying student teachers' inquiry-related questions in biology lessons. *Education Sciences*, *11*(2), 87. https://doi.org/10.3390/educsci11020087

Hiltunen, M., Kärkkäinen, S., Keinonen, T., Hahkioniemi, M., Lehesvuori, S., & Tikkanen, P. (2016). PRIMARY SCHOOL STUDENT TEACHERS´ CLASSROOM TALK DURING INQUIRY-BASED BIOLOGY LESSONS. *Problems of Education in the 21st Century*, *69*(1), 37–56. https://doi.org/10.33225/pec/16.69.37

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A Response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, *42*(2), 99–107. https://doi.org/10.1080/00461520701263368

Huibregtse, I., Korthagen, F., & Wubbels, T. (1994). Physics teachers' conceptions of learning, teaching and professional development. *International Journal of Science Education*, *16*(5), 539–561. https://doi.org/10.1080/0950069940160505

Hwang, S., Kim, N., Jeon, S. H., Shim, H. P., & Ryu, K. B. (2018). Analyzing the growth of a pre-service science teacher community through the lens of cultural historical activity theory: The case of a three-year voluntary science teaching program. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(4), 1133–1145. https://doi.org/10.29333/ejmste/81810

Inel-Ekici, D., & Ekici, M. (2021). Mobile inquiry and inquiry-based science learning in higher education: Advantages, challenges, and attitudes. *Asia Pacific Education Review*, *23*(3), 1–18. https://doi.org/10.1007/s12564-021-09729-2

Irwanto Saputro, A. D., Rohaeti, E., & Prodjosantoso, A. K. (2019). Using inquiry-based laboratory instruction to improve critical thinking and scientific process skills among preservice elementary teachers. *Eurasian Journal of Educational Research*, (80), 151–170. https://doi.org/10.14689/ejer.2019.80.8

Isabelle, A. D., & de Groot, C. (2008). Alternate conceptions of preservice elementary teachers: The Itakura method. *Journal of Science Teacher Education*, *19*(5), 417–435. https://doi.org/10.1007/s10972-008-9105-8

Itakura, K. (1967). Instruction and learning of concept ''force'' in static based on kasetsi–jikken–jiggo (hypothesis–experiment–instruction): A new model of teaching science. *Bulletin of National Institute for Educational Research*, *52*, 1–121.

Jeenjenkit, U., Magee, P. A., Barman, N., Ruenwongsa, P., & Panijpan, B. (2011). An inquiry learning unit for enhancing elementary pre-service teacher understanding of factors affecting chemical reaction rate. *International Journal of Learning*, *17*(10), 309–328.

Jones, M. G., & Leagon, M. (2014). Science teacher attitudes and beliefs: Reforming practice. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education, volume II* (pp. 844–861). Routledge.

Kang, E. J., Bianchini, J. A., & Kelly, G. J. (2013). Crossing the border from science student to science teacher: Preservice teachers' views and experiences learning to teach inquiry. *Journal of Science Teacher Education*, *24*(3), 427–447. https://doi.org/10.1007/s10972-012-9317-9

Kapucu, S. (2016). Guided inquiry-based electricity experiments: Pre-service elementary science teachers' difficulties. *Journal of Education and Future*, 10, 71–93.

Karea, S., Asrial, A., Kurniawan, D. A., Perdana, R., & Pratama, R. A. (2021). Implementing inquiry based ethno-constructivism learning module to improve students' critical thinking skills and attitudes towards cultural values. *Eurasian Journal of Educational Research*, *2021*(95), 118–138. https://doi.org/10.14689/ejer.2021.95.7

Kazempour, M., & Amirshokoohi, A. (2013). Exploring elementary pre-service teachers' experiences and learning outcomes in a revised inquiry-based science lesson: An action research. *Journal of Education and Learning*, *2*(2), 144–154. https://doi.org/10.5539/jel.v2n2p144

Kelchtermans, G., Smith, K., & Vanderlinde, R. (2018). Towards an 'international forum for teacher educator development': An agenda for research and action. *European Journal of Teacher Education*, *41*(1), 120–134. https://doi.org/10.1080/02619768.2017.1372743

Kim, B. S. (2010). Integration of service-learning into elementary science teaching methods courses. *International Journal of Learning*, *17*(8), 321–330. https://doi.org/10.18848/1447-9494/CGP/v17i08/47208

Kinyota, M., & Rwimo, B. S. (2021). Developing student teachers' conceptions of the nature of science: An assessment of a pre-service science teacher programme in Tanzania. *African Journal of Research in Mathematics, Science and Technology Education*, *25*(3), 269–279. https://doi.org/10.1080/18117295.2022.2041788

Kıran, D. (2022). Examining the efficacy change of preservice science teachers: Does an inquiry-based laboratory instruction make a difference? A mixed method study. *International Journal of Science Education*, *44*(9), 1–22. https://doi.org/10.1080/09500693.2022.2084171

Kirschner, P., Sweller, J., & Clark, R. E. (2006). Why unguided learning does not work: An analysis of the failure of discovery learning, problem-based learning, experiential learning and inquiry-based learning. *Educational Psychologist*, *41*(2), 75–86. https://doi.org/10.1207/s15326985ep4102_1

Krämer, P., Nessler, S. H., & Schlüter, K. (2015). Teacher students' dilemmas when teaching science through inquiry. *Research in Science & Technological Education*, *33*(3), 325–343. https://doi.org/10.1080/02635143.2015.1047446

Kukkonen, J., Dillon, P., Kärkkäinen, S., Hartikainen-Ahia, A., & Keinonen, T. (2016). Pre-service teachers' experiences of scaffolded learning in science through a computer supported collaborative inquiry. *Education and Information Technologies*, *21*(2), 349–371. https://doi.org/10.1007/s10639-014-9326-8

Lederman, N. G., & Lederman, J. S. (2014). Research on teaching and learning of nature of science. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education, volume II* (pp. 600–620). Routledge.

Lee, C. K., & Shea, M. (2016). An analysis of pre-service elementary teachers' understanding of inquiry-based science teaching. *Science Education International*, *27*(2), 219–237.

Leonard, J., Barnes-Johnson, J., Dantley, S. J., & Kimber, C. (2011). Teaching science inquiry in urban contexts: The role of elementary preservice teachers' beliefs. *Urban Review: Issues and Ideas in Public Education*, *43*(1), 124–150. https://doi.org/10.1007/s11256-010-0173-7

Leonard, J., Boakes, N., & Moore, C. M. (2009). Conducting science inquiry in primary classrooms: Case studies of two preservice teachers' inquiry-based practices. *Journal of Elementary Science Education*, *21*(1), 27–50. https://doi.org/10.1007/BF03174714

Lotter, C., Singer, J., & Godley, J. (2009). The influence of repeated teaching and reflection on preservice teachers' views of inquiry and nature of science. *Journal of Science Teacher Education*, *20*(6), 553–582. https://doi.org/10.1007/s10972-009-9144-9

Luera, G. R., Moyer, R. H., & Everett, S. A. (2005). What type and level of science content knowledge of elementary education students affect their ability to construct an inquiry-based science lesson? *Journal of Elementary Science Education*, *17*(1), 12–25. https://doi.org/10.1007/BF03174670

Lunenberg, M., Korthagen, F., & Swennen, A. (2007). The teacher educator as a role model. *Teaching and Teacher Education*, *23*(5), 586–601. https://doi.org/10.1016/j.tate.2006.11.001

Lustick, D. (2009). The failure of inquiry: Preparing science teachers with an authentic investigation. *Journal of Science Teacher Education*, *20*(6), 583–604. https://doi.org/10.1007/s10972-009-9149-4

Magee, P. A., & Flessner, R. (2012). Collaborating to improve inquiry-based teaching in elementary science and mathematics methods courses. *Science Education International*, *23*(4), 353–365. https://doi.org/10.1080/10476210.2012.727794

Ma, A., van der Flier-Keller, E., Zandvliet, D., & Cameron, K. (2022). Merging earth science into an environmental education course for K-12 teachers: Is it successful? *Journal of Geoscience Education*, *70*(2), 223–237. https://doi.org/10.1080/10899995.2021.2009624

McCullagh, J., & Doherty, A. (2021). A coteaching model for developing pre-service teachers' practice and confidence in teaching primary science through inquiry. *Education 3-13*, *49*(3), 357–370. https://doi.org/10.1080/03004279.2020.1854963

McDonald, S., Grimes, P., Doughty, L., Finlayson, O., McLoughlin, E., & van Kampen, P. (2019). A workshop approach to developing the professional pedagogical vision of Irish secondary pre-service science teachers. *Journal of Science Teacher Education*, *30*(5), 434–460. https://doi.org/10.1080/1046560X.2019.1583033

Meyer, D., Meyer, A. A., Nabb, K., Connell, M., & Avery, L. (2013). A theoretical and empirical exploration of intrinsic problems in designing inquiry activities. *Research in Science Education*, *43*(1), 57–76. https://doi.org/10.1007/s11165-011-9243-4

Morrison, J. A. (2008). Individual inquiry investigations in an elementary science methods course. *Journal of Science Teacher Education*, *19*(2), 117–134. https://doi.org/10.1007/s10972-007-9086-z

Mortimer, E. F., & Scott, P. H. (2003). *Meaning making in secondary science classrooms*. Open University Press.

Muñoz-Franco, G., Criado, A. M., & García-Carmona, A. (2020). Investigating image formation with a camera obscura: A study in initial primary science teacher education. *Research in Science Education*, *50*(3), 1027–1049. https://doi.org/10.1007/s11165-018-9721-z

Namdar, B. (2018). Teaching global climate change to pre-service middle school teachers through inquiry activities. *Research in Science & Technological Education*, *36*(4), 440–462. https://doi.org/10.1080/02635143.2017.1420643

National Research Council. (1996) . *National science education standards*. National Academies Press.

National Research Council. (2000). *Inquiry and the National science education standards: A guide for teaching and learning*. The National Academies Press. https://doi.org/10.17226/9596

National Research Council. (2012) . *A framework for K-12 Science Education: Practices, crosscutting concepts, and core ideas*. National Academies Press.

Nawanidbumrung, W., Samiphak, S., & Inoue, N. (2022). The impact of pre-service teachers' pedagogical beliefs on teaching science as inquiry: A silent antagonist for effective inquiry-based science lessons. *Science Education International*, *33*(1), 112–121. https://doi.org/10.33828/sei.v33.i1.12

Nesmith, S., Ditmore, E., Scott, L., & Zhu, T. (2017). "This is more about a book than about science!" Preservice teachers' perceptions toward using literacy strategies in inquiry-based science lessons. *Electronic Journal of Science Education*, *21*(5), 1–13. https://doi.org/10.14689/issn.2148-2624.1.5c2s1m

Nhlengethwa, K. B., Govender, N., & Sibanda, D. (2020). Final-year pre-service primary school teachers' understanding of inquiry-based-science teaching. *Journal of Baltic Science Education*, *19*(3), 454–466. https://doi.org/10.33225/jbse/20.19.454

Nhlengethwa, K. B., Govender, N., & Sibanda, D. (2021). Primary school pre-service teachers' enactment of inquiry-based-science teaching. *Education 3-13*, *49*(3), 288–301. https://doi.org/10.1080/03004279.2020.1854958

Nivalainen, V., Asikainen, M., & Hirvonen, P. (2013). Open guided inquiry laboratory in physics teacher education. *Journal of Science Teacher Education*, *24*(3), 449–474. https://doi.org/10.1007/s10972-012-9316-x

Nugent, G., Toland, M., Levy, R., Kunz, G., Harwood, D., Green, D., & Kitts, K. (2012). The impact of an inquiry-based geoscience field course on pre-service teachers. *Journal of Science Teacher Education*, *23*(5), 503–529. https://doi.org/10.1007/s10972-012-9283-2

OECD. (2020). *PISA 2024 Strategic Vision and Direction for Science*. https://www.oecd.org/pisa/publications/PISA-2024-Science-Strategic-Vision-Proposal.pdf

Oh, P. S. (2011). Characteristics of abductive inquiry in earth science: An undergraduate case study. *Science Education*, *95*(3), 409–430. https://doi.org/10.1002/sce.20424

Okulu, H. Z., & Ünver, A. O. (2018). The process of facilitating knowledge acquisition and retention: An inquiry into magnetic poles with challenging questions. *International Education Studies*, *11*(5), 25–37. https://doi.org/10.5539/ies.v11n5p25

Önder, F., Senyigit, C., & Silay, I. (2018). Effect of an inquiry-based learning method on students' misconceptions about charging of conducting and insulating bodies. *European Journal of Physics*, *39*(5), 1–14. https://doi.org/10.1088/1361-6404/aac52a

Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science*, *328*(5977), 463–466. https://doi.org/10.1126/science.1183944

Otto, C., Everett, S., Moyer, R., & Zitzewitz, P. (2012). Using a state teacher certification test to assess an inquiry-based science education program. *International Journal of Science & Mathematics Education*, *10*(3), 531–552. https://doi.org/10.1007/s10763-011-9296-x

Ozdem, Y., Ertepinar, H., Cakiroglu, J., & Erduran, S. (2013). The nature of pre-service science teachers' argumentation in inquiry-oriented laboratory context. *International Journal of Science Education*, *35*(15), 2559–2586. https://doi.org/10.1080/09500693.2011.611835

Özer, F., & Sarıbaş, D. (2022). Exploring pre-service science teachers' understanding of scientific inquiry and scientific practices through a laboratory course. *Science & Education*, 1–34. https://doi.org/10.1007/s11191-022-00325-3

Ozgelen, S., Yilmaz-Tuzun, O., & Hanuscin, D. (2013). Exploring the development of preservice science teachers' views on the nature of science in inquiry-based laboratory instruction. *Research in Science Education*, *43*(4), 1551–1570. https://doi.org/10.1007/s11165-012-9321-2

Papaevripidou, M., Irakleous, M., & Zacharia, Z. C. (2017). Using teachers' inquiry-oriented curriculum materials as a means to examine their pedagogical design capacity and pedagogical content knowledge for inquiry-basedlearning. *Science Education International*, *28*(4), 271–292.

Park, J., Chang, J., Park, J., & Yoon, H. -G. (2022). Features of and representational strategies in instructional videos for primary science classes. *International Journal of Science Education*, *44*(16), 2397–2422. https://doi.org/10.1080/09500693.2022.2126289

Pérez, B. C. (2022). Epistemic criteria considered by pre-service teachers for assessing the quality of a scientific investigation about friction force. *Research in Science Education*, *52*(2), 459–472. https://doi.org/10.1007/s11165-020-09958-2

Pérez, B. C., & Díaz-Moreno, N. (2021). Promoting pre-service primary teachers' development of NOSI through specific immersion and reflection. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(3), em2089. https://doi.org/10.29333/ejmste/11795

Pilitsis, V., & Duncan, R. G. (2012). Changes in belief orientations of preservice teachers and their relation to inquiry activities. *Journal of Science Teacher Education*, *23*(8), 909–936. https://doi.org/10.1007/s10972-012-9303-2

Plummer, J. D., & Ozcelik, A. T. (2015). Preservice teachers developing coherent inquiry investigations in elementary astronomy. *Science Education*, *99*(5), 932–957. https://doi.org/10.1002/sce.21180

Plummer, J. D., Zahm, V. M., & Rice, R. (2010). Inquiry and astronomy: Preservice teachers' investigations of celestial motion. *Journal of Science Teacher Education*, *21*(4), 471–493. https://doi.org/10.1007/s10972-010-9189-9

Prayogi, S., & Verawati, N. N. S. P. (2020). The effect of conflict cognitive strategy in inquiry-based learning on preservice teachers' critical thinking ability. *Journal of Educational, Cultural and Psychological Studies (ECPS Journal)*, (21), 27–41. https://doi.org/10.7358/ecps-2020-021-pray

Puvirajah, A. (2007). *Exploring the Quality and Credibility of Students' Argumentation: Teacher Facilitated Technology Embedded Scientific Inquiry* [Doctoral dissertation, Wayne State

University]. ProQuest Dissertations Publishing. https://www.proquest.com/docview/304799183?pq-origsite=gscholar&fromopenview=true
Qablan, A. M., Al-Ruz, J. A., Theodora, D., & Al-Momani, I. (2009). "I know it's so good, but i prefer not to use it" an interpretive investigation of Jordanian preservice elementary teachers' perspectives about learning biology through inquiry. *International Journal of Teaching and Learning in Higher Education*, *20*(3), 394–404.
Qablan, A. M., & DeBaz, T. (2015). Facilitating elementary science teachers' implementation of inquiry-based science teaching. *Teacher Development*, *19*(1), 3–21. https://doi.org/10.1080/13664530.2014.959552
Rees, C., Pardo, R., & Parker, J. (2013). Steps to opening scientific inquiry: Pre-service teachers' practicum experiences with a new support framework. *Journal of Science Teacher Education*, *24*(3), 475–496. https://doi.org/10.1007/s10972-012-9315-y
Richardson, G. M., & Liang, L. L. (2008). The use of inquiry in the development of preservice teacher efficacy in mathematics and science. *Journal of Elementary Science Education*, *20*(1), 1–16. https://doi.org/10.1007/BF03174699
Richardson, G. M., Liang, L. L., & Wake, D. G. (2014). Examining the durability of environmental education self-efficacy beliefs in preservice teaching. *Applied Environmental Education and Communication*, *13*(1), 38–47. https://doi.org/10.1080/1533015X.2014.913963
Riegle-crumb, C., Morton, K., Moore, C., Chimonidou, A., Labrake, C., & Kopp, S. (2015). Do inquiring minds have positive attitudes? The science education of preservice elementary teachers. *Science Education*, *99*(5), 819–836. https://doi.org/10.1002/sce.21177
Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henriksson, H., & Hemmo, V. (2007). Rocard report: "Science education now: A new pedagogy for the future of Europe". *EU 22845*, *European Commission*.
Rohaeti, E., & Prodjosantoso, A. K. (2020). Oriented collaborative inquiry learning model: Improving students' scientific attitudes in general chemistry. *Journal of Baltic Science Education*, *19*(1), 108–120. https://doi.org/10.33225/jbse/20.19.108
Rönnebeck, S., Bernholt, S., & Ropohl, M. (2016). Searching for a common ground: A literature review of empirical research on scientific inquiry activities. *Studies in Science Education*, *52*(2), 161–197. https://doi.org/10.1080/03057267.2016.1206351
Salter, I. Y., & Atkins, L. J. (2013). What students say versus what they do regarding scientific inquiry. *Science Education*, *98*(1), 1–35. https://doi.org/10.1002/sce.21084
Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education*, *89*(4), 634–656. https://doi.org/10.1002/sce.20065
Sanger, M. J. (2007). The effects of inquiry-based instruction on elementary teaching majors' chemistry content knowledge. *Journal of Chemical Education*, *84*(6), 1035–1039. https://doi.org/10.1021/ed084p1035
Sanger, M. J. (2008). How does inquiry-based instruction affect teaching majors' views about teaching and learning science? *Journal of Chemical Education*, *85*(2), 297–302. https://doi.org/10.1021/ed085p297
Saribas, D. (2015). Pre-service elementary teachers' preferences and competencies in relation to inquiry-based instruction and high quality questions. *The Anthropologist*, *22*(2), 227–236. https://doi.org/10.1080/09720073.2015.11891873
Schmidt, M., & Fulton, L. (2017). Lessons learned from creation of an exemplary STEM unit for elementary pre-service teachers: A case study. *Journal of Computers in Mathematics & Science Teaching*, *36*(2), 189–204.
Schwarz, C. V. (2009). Developing preservice elementary teachers' knowledge and practices through modeling-centered scientific inquiry. *Science Education*, *93*(4), 720–744. https://doi.org/10.1002/sce.20324
Schwarz, C. V., & Gwekwerere, Y. N. (2007). Using a guided inquiry and modeling instructional framework (EIMA) to support preservice K-8 science teaching. *Science Education*, *91*(1), 158–186. https://doi.org/10.1002/sce.20177
Sen, C., & Vekli, G. S. (2016). The impact of inquiry based instruction on science process skills and self-efficacy perceptions of pre-service science teachers at a university level biology laboratory.

Universal Journal of Educational Research, *4*(3), 603–612. https://doi.org/10.13189/ujer.2016.040319

Seung, E., Park, S., & Jung, J. (2014). Exploring preservice elementary teachers' understanding of the essential features of inquiry-based science teaching using evidence-based reflection. *Research in Science Education*, *44*(4), 507–529. https://doi.org/10.1007/s11165-013-9390-x

Shively, C. T., & Yerrick, R. K. (2014). A case for examining pre-service teacher preparation for inquiry teaching science with technology. *Research in Learning Technology*, *22*, 1–13. https://doi.org/10.3402/rlt.v22.21691

Sickel, A. J., & Witzig, S. B. (2017). Science methods courses across contexts. In A. J. Sickel & S. B. Witzig (Eds.), *Designing and teaching the secondary science methods course: An international perspective*, (pp. 225-250). Sense Publishers.

Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education*, *28*(2–3), 235–260. https://doi.org/10.1080/09500690500336957

Sjøberg, S. (2019). *Critical perspectives on inquiry-based science education (IBSE) in Europe*. EUN Partnership, European Schoolnet.

Smolleck, L. A., & Yoder, E. P. (2008). Further development and validation of the teaching science as inquiry (TSI) instrument. *School Science & Mathematics*, *108*(7), 291–297. https://doi.org/10.1111/j.1949-8594.2008.tb17842.x

Soprano, K., & Yang, L. L. (2013). Inquiring into my science teaching through action research: A case study on one pre-service teacher's inquiry-based science teaching and self-efficacy. *International Journal of Science & Mathematics Education*, *11*(6), 1351–1368. https://doi.org/10.1007/s10763-012-9380-x

Soulios, I., & Psillos, D. (2016). Enhancing student teachers' epistemological beliefs about models and conceptual understanding through a model-based inquiry process. *International Journal of Science Education*, *38*(7), 1212–1233. https://doi.org/10.1080/09500693.2016.1186304

Stuchlikova, I., Petr, J., & Papacek, M. (2013). Inquiry-based teaching and future teachers' attitutes towards it. In M. H. Hoveid & P. Gray (Eds.), *Inquiry in science education and science teacher education - Research on teaching and learning through inquiry based approaches in science (teacher) education* (pp. 167–186). Akademika forlag.

Sutton, A., Clowes, M., Preston, L., & Booth, A. (2019). Meeting the review family: Exploring review types and associated information retrieval requirements. *Health Information & Libraries Journal*, *36*(3), 202–222. https://doi.org/10.1111/hir.12276

Syer, C. A., Chichekian, T., Shore, B. M., & Aulls, M. W. (2013). Learning "to do" and learning "about" inquiry at the same time: Different outcomes in valuing the importance of various intellectual tasks in planning, enacting, and evaluating an inquiry curriculum. *Instructional Science*, *41*(3), 521–537. https://doi.org/10.1007/s11251-012-9242-5

Tatar, N. (2012). Inquiry-based science laboratories: An analysis of preservice teachers' beliefs about learning science through inquiry and their performances. *Journal of Baltic Science Education*, *11*(3), 248–266. https://doi.org/10.33225/jbse/12.11.248

Tessier, J. (2010). An inquiry-based biology laboratory improves preservice elementary teachers' attitudes about science. *Journal of College Science Teaching*, *39*(6), 84–90.

Thompson, S., Lotter, C., Fann, X., & Taylor, L. (2016). Enhancing elementary pre-service teachers' plant processes conceptions. *Journal of Science Teacher Education*, *27*(4), 439–463. https://doi.org/10.1007/s10972-016-9469-0

Ucar, S., & Trundle, K. C. (2011). Conducting guided inquiry in science classes using authentic, archived, web-based data. *Computers & Education*, *57*(2), 1571–1582. https://doi.org/10.1016/j.compedu.2011.02.007

Ucar, S., Trundle, K. C., & Krissek, L. (2011). Inquiry-based instruction with archived, online data: An intervention study with preservice teachers. *Research in Science Education*, *41*(2), 261–282. https://doi.org/10.1007/s11165-009-9164-7

Uitto, M., Jokikokko, K., & Estola, E. (2015). Virtual special issue on teachers and emotions in Teaching and teacher education (TATE) in 1985–2014. *Teaching and Teacher Education*, *50*, 124–135. https://doi.org/10.1016/j.tate.2015.05.008

Valente, B., Maurício, P., & Faria, C. (2022). The influence of real-context scientific activities on preservice elementary teachers' thinking and practice of nature of science and scientific inquiry. *Science & Education*, 1–23. https://doi.org/10.1007/s11191-022-00377-5

Valls-Bautista, C., Solé-LLussà, A., & Casanoves, M. (2021). Pre-service teachers' acquisition of scientific knowledge and scientific skills through inquiry-based laboratory activity. *Higher Education, Skills and Work-Based Learning*, *11*(5), 1160–1179. https://doi.org/10.1108/HESWBL-07-2020-0161

Van Uum, M. S., Verhoeff, R. P., & Peeters, M. (2016). Inquiry-based science education: Towards a pedagogical framework for primary school teachers. *International Journal of Science Education*, *38*(3), 450–469. https://doi.org/10.1080/09500693.2016.1147660

Varma, T. (2011). Elementary pre-service teachers' personal science pedagogy concept development and confidence to teach science. *Global Education Journal*, *1*(2), 76–106.

Varma, T., Volkmann, M., & Hanuscin, D. (2009). Preservice elementary teachers' perceptions of their understanding of inquiry and inquiry-based science pedagogy: Influence of an elementary science education methods course and a science field experience. *Journal of Elementary Science Education*, *21*(4), 1–22. https://doi.org/10.1007/BF03182354

Verawati, N. N. S. P., Hikmawati, H., & Prayogi, S. (2020). The effectiveness of inquiry learning models intervened by reflective processes to promote critical thinking ability in terms of cognitive style. *International Journal of Emerging Technologies in Learning*, *15*(16), 212–220. https://doi.org/10.3991/ijet.v15i16.14687

Wang, J. (2020). Compare inquiry-based pedagogical instruction with direct instruction for pre-service science teacher education. *International Journal of Science and Mathematics Education*, *18*(6), 1063–1083. https://doi.org/10.1007/s10763-019-10010-7

Wang, J., & Sneed, S. (2019). Exploring the design of scaffolding pedagogical instruction for elementary preservice teacher education. *Journal of Science Teacher Education*, *30*(5), 483–506. https://doi.org/10.1080/1046560X.2019.1583035

Wang, H. -H., Wilson, K., VanRooy, W., & Lin, H. -S. (2022). Pre-service primary teachers' competencies in asking and conducting researchable science questions using fair testing. *Research in Science Education*, *53*(1), 155–171. https://doi.org/10.1007/s11165-022-10048-8

Weld, J., & Funk, L. (2005). "I'm Not the Science Type": Effect of an inquiry biology content course on preservice elementary teachers' intentions about teaching science. *Journal of Science Teacher Education*, *16*(3), 189–204. https://doi.org/10.1007/s10972-005-4860-2

Windschitl, M. (2003). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education*, *87*(1), 112–143. https://doi.org/10.1002/sce.10044

Winje, Ø., & Løndal, K. (2020). Bringing deep learning to the surface: A systematic mapping review of 48 years of research in primary and secondary education. *Nordic Journal of Comparative and International Education*, *4*(2), 25–41. https://doi.org/10.7577/njcie.3798

Yakar, Z., & Baykara, H. (2014). Inquiry-based laboratory practices in a science teacher training program. *EURASIA Journal of Mathematics, Science & Technology Education*, *10*(2), 173–183. https://doi.org/10.12973/eurasia.2014.1058a

Yerrick, R. K., Ambrose, R., & Schiller, J. (2008). Ascribing legitimacy: Pre-service teachers construction of science teaching expertise in multiple communities. *Electronic Journal of Science Education*, *12*(2), 132–170.

Yoon, H. -G., Joung, Y. J., & Kim, M. (2012). The challenges of science inquiry teaching for pre-service teachers in elementary classrooms: Difficulties on and under the scene. *Research in Science Education*, *42*(3), 589–608. https://doi.org/10.1007/s11165-011-9212-y

Yoon, H. -G., Kim, M., Kim, B. S., Joung, Y. J., & Park, Y. -S. (2013). Pre-service teachers' views of inquiry teaching and their responses to teacher educators' feedback on teaching practice. *EURASIA Journal of Mathematics, Science & Technology Education*, *9*(4), 347–359. https://doi.org/10.12973/eurasia.2013.944a

Zhang, L., & Cobern, W. W. (2020). Confusions on "guidance" in inquiry-based science teaching: A response to Aditomo and Klieme 2020. *Canadian Journal of Science, Mathematics and Technology Education*, *21*(1), 1–6. https://doi.org/10.1007/s42330-020-00116-4

Zhou, G., & Xu, J. (2017). Microteaching lesson study: An approach to prepare teacher candidates to teach science through inquiry. *International Journal of Education in Mathematics, Science and Technology*, *5*(3), 235–247. https://doi.org/10.18404/ijemst.296039

Zulfiani, Z., & Herlanti, Y. (2018). Scientific inquiry perception and ability of pre-service teachers. *Journal of Turkish Science Education*, *15*(1), 128–140. https://doi.org/10.12973/tused.10225a

Appendix

Appendix A. A general overview of the included articles

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
1	Acarli, D.S.; Dervisoglu, S.	2021	Journal of Educational Studies Trend and Practices	Effect of inquiry-based biology laboratory applications on scientific process skills, attitude, self-efficacy and self-confidence	Turkey	Quantitative	25	IBL	Procedural, Affective	Not specified
2	Aidoo, B. Anthony-Krueger, C. Gyampoh, A. Obiri G. Tsyawo, J. Quansah, F.	2022	European Journal of Science and Mathematics Education	A mixed-method approach to investigate the effect of flipped inquiry-based learning on chemistry students learning	Ghana	Mixed Methods	100	IBL	Conceptual, Affective, Other	Not specified
3	Akgul, E.M.	2006	EURASIA Journal of Mathematics, Science & Technology Education	Teaching science in an inquiry-based learning environment: what it means for pre-service elementary science teachers	Turkey	Qualitative	34	IBL	Epistemic, Pedagogical	Elementary
4	Amos, R. Levinson, R.	2019	International Journal of Development Education & Global Learning	Socio-scientific inquiry-based learning: an approach for engaging with the 2030 Sustainable Development Goals through school science	UK	Quantitative	350	IBT	Pedagogical	Not specified
5	Arabacioglu, S. Unver, A. O.	2016	Journal of Baltic Science Education	Supporting inquiry based laboratory practices with mobile learning to enhance students' process skills in science education	Turkey	Qualitative	11	IBL	Procedural, Other	Elementary
6	Arsal, Z.	2017	International Journal of Science Education	The impact of inquiry-based learning on the critical thinking dispositions of pre-service science teachers	Turkey	Qualitative	56	IBL	Other	Not specified
7	Asy'ari, M. Ikhsan, M. Muhali	2019	International Journal of Instruction	The effectiveness of inquiry learning model in improving prospective teachers' metacognition knowledge and metacognition awareness	Indonesia	Quantitative	90	IBL	Other	Not specified
8	Avery, L.M. Meyer, D.Z.	2012	School Science & Mathematics	Teaching science as science is practiced: opportunities and limits for enhancing preservice elementary teachers' self-efficacy for science and science teaching	USA	Mixed Methods	77	IBL	Affective	Elementary

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
9	Aydin, M.	2019	Journal of Biological Education	Investigating pre-service science teachers mobile augmented reality integration into worksheets	Turkey	Mixed Methods	81	IBT	Other	Not specified
10	Bansal, G.	2020	Education 3–13	Indian pre-service teachers' conceptualisations and enactment of inquiry-based science education	India	Mixed Methods	4	IBT	Pedagogical	Middle
11	Baxter, B.K. Jenkins, C.C. Southerland, S. A. Wilson, P.	2004	Journal of Science Teacher Education	Using a multilevel assessment scheme in reforming science methods courses	USA	Mixed Methods	69	IBT	Procedural, Pedagogical	Secondary
12	Bhattacharyya, S. Volk, T. Lumpe, A.	2009	Journal of Science Teacher Education	The influence of an extensive inquiry-based field experience on pre-service elementary student teachers' science teaching beliefs	USA	Mixed Methods	14	IBT	Affective	Elementary
13	Biggers, M. Forbes, C.T.	2012	International Journal of Science Education	Balancing teacher and student roles in elementary classrooms: preservice elementary teachers' learning about the inquiry continuum	USA	Qualitative	6	IBT	Pedagogical, Affective	Elementary
14	Binns, I.C. Popp, S.	2013	Electronic Journal of Science Education	Learning to teach science through inquiry: experiences of preservice teachers	USA	Qualitative	7	IBT	Pedagogical, Affective	Secondary
15	Britner, S.L. Finson, K.D.	2005	Journal of Elementary Science Education	Preservice teachers' reflections on their growth in an inquiry-oriented science pedagogy course	USA	Qualitative	34	IBT	Procedural, Affective	Not specified
16	Bruckermann, T. Aschermann, E. Bresges, A. Schlüter, K.	2017	International Journal of Science Education	Metacognitive and multimedia support of experiments in inquiry learning for science teacher preparation	Germany	Mixed Methods	63	IBL	Procedural, Other	Lower secondary
17	Bryant R.	2006	Journal of College Science Teaching	Assessment Results Following Inquiry and Traditional Physics Laboratory Activities	USA	Qualitative	51	IBL	Procedural, Conceptual	Elementary
18	Buyruk, A.A Bekiroglu, F.O.	2018	Journal of Education in Science, Environment and Health	Comparison of pre-service physics teachers' conceptual understanding of dynamics in model-based scientific inquiry and scientific inquiry environments	Turkey	Mixed Methods	22	IBL	Conceptual	Secondary
19	Cartwright, T. Smith, S. Hallar, B.	2014	Teacher Education & Practice	Confronting barriers to teaching elementary science: after-school science teaching experiences for preservice teachers	USA	Qualitative	8	IBT	Affective	Elementary

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
20	Cian, H. Dsouza, N. Lyons, R. Cook, M.	2017	Journal of Science Teacher Education	Influences on the development of inquiry-based practices among preservice teachers	USA	Qualitative	4	IBT	Pedagogical	Secondary
21	Crawford, B.A. Zembal-Saul, C. Munford, D. Friedrichsen, P.	2005	Journal of Research in Science Teaching	Confronting prospective teachers' ideas of evolution and scientific inquiry using technology and inquiry-based tasks	USA	Qualitative	21	IBL	Epistemic, Conceptual, Other	Secondary
22	Cruz-Guzman, M. Garcia-Carmona, A. Criado, A. M.	2017	International Journal of Science Education	An analysis of the questions proposed by elementary pre-service teachers when designing experimental activities as inquiry	Spain	Qualitative	154	IBL	Procedural	Elementary
23	Cruz-Guzman, M.; Garciá-Carmona, A.; Criado, A.M.	2020	Research in Science Education	Proposing questions for scientific inquiry and the selection of science content in initial elementary education teacher training	Spain	Qualitative	67	IBL	Procedural	Elementary
24	Del Greco, R. Bernadowski, C. Parker, S.	2018	International Journal of Instruction	Using illustrations to depict preservice science teachers' self-efficacy: a case study	USA	Qualitative	80	IBT	Affective	Elementary
25	Docherty-Skippen, S.M.; Karrow, D.; Ahmed, G.	2020	Brock Education Journal: A Journal of Educational Research and Practice	Doing science: pre-service teachers' attitudes and confidence teaching elementary science and technology	Canada	Quantitative	27	IBL	Affective	Elementary
26	Duncan, R.G. Pilitsis, V. Piegaro, M.	2010	Journal of Science Teacher Education	Development of preservice teachers' ability to critique and adapt inquiry-based instructional materials	USA	Qualitative	17	IBT	Procedural	Secondary
27	Duran, L.B. McArthur, J. Van Hook, S.	2004	Journal of Science Teacher Education	Undergraduate students' perceptions of an inquiry-based physics course	USA	Qualitative	25	IBL	Affective	Not specified
28	Ecevit, T. Kaptan, F.	2022	Journal of Theoretical Educational Science	The efficiency of argument-based inquiry practices in science teacher candidate education	Turkey	Mixed Methods	38	IBL	Epistemic, Procedural, Other	Not specified

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
29	Eick, C.J.	2000	Electronic Journal of Science Education	Inquiry, nature of science, and evolution: the need for a more complex pedagogical content knowledge in science teaching	USA	Qualitative	12	IBT	Epistemic	Secondary
30	Eick, C. Dias, M.	2005	Science Education	Building the authority of experience in communities of practice: the development of preservice teachers' practical knowledge through coteaching in inquiry classrooms	USA	Qualitative	11	IBT	Pedagogical	Secondary
31	Eick, C.J. Reed, C.J.	2002	Science Education	What makes an inquiry-oriented science teacher? The influence of learning histories on teacher role identity and practice	USA	Qualitative	12	IBT	Pedagogical, Affective	Secondary
32	Enugu, R. Hokayem, H.	2017	European Journal of Science and Mathematics Education	Challenges pre-service teachers face when implementing a 5E inquiry model of instruction	USA	Qualitative	55	IBT	Procedural	Elementary
33	Fazio, X. Melville, W. Bartley, A.	2010	Journal of Science Teacher Education	The problematic nature of the practicum: a key determinant of pre-service teachers' emerging inquiry-based science practices	Canada	Mixed Methods	107	IBT	Affective	Secondary
34	Feyzioglu, B.	2019	International Journal of Education in Mathematics, Science and Technology	Examination of laboratory perceptions of pre-service science teachers with different goal orientations on inquiry-based analytical chemistry courses: a case study	Turkey	Qualitative	37	IBL	Procedural	Not specified
35	Forbes, C.	2013	Journal of Science Teacher Education	Curriculum-dependent and curriculum-independent factors in preservice elementary teachers' adaptation of science curriculum materials for inquiry-based science	USA	Mixed Methods	46	IBT	Procedural	Elementary
36	Garcia-Carmona, A.	2017	International Journal of Science & Mathematics Education	Pre-service primary science teachers' abilities for solving a measurement problem through inquiry	Spain	Qualitative	23	IBL	Procedural	Primary

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
37	García-Carmona, A. Criado, A. Cruz-Guzmán, M.	2016	Research in Science Education	Primary pre-service teachers' skills in planning a guided scientific inquiry	Spain	Qualitative	66	IBL	Procedural	Primary
38	Gencer, S. Ekici, F.	2022	Journal of Chemical Education	Preservice chemistry teachers' understanding of surface tension through guided-inquiry	Turkey	Qualitative	10	IBL	Conceptual	Not specified
39	Gilbert, A.	2009	Early Childhood Education Journal	Utilizing science philosophy statements to facilitate K-3 teacher candidates' development of inquiry-based science practice	USA	Qualitative	40	IBT	Pedagogical	Not specified
40	Glackin, M. Harrison, C.	2018	Journal of Biological Education	Budding biology teachers: what have botanical gardens got to offer inquiry learning	UK	Qualitative	8	IBL	Pedagogical	Secondary
41	Goldston, M. Dantzler, J. Day, J. Webb, B.	2013	Journal of Science Teacher Education	A psychometric approach to the development of a 5E lesson plan scoring instrument for inquiry-based teaching	USA	Mixed Methods	224	IBT	Procedural	Elementary
42	Graves, C. Rutherford, S.	2012	Journal of College Science Teaching	Writing a scientific research ('testable') question: the first step in using online data sets for guided inquiry assignments	USA	Mixed Methods	109	IBL	Procedural	Elementary
43	Greca, I.M.	2016	International Journal of Science Education	Supporting pre-service elementary teachers in their understanding of inquiry teaching through the construction of a third discursive space	Spain	Qualitative	3	IBT	Pedagogical	Elementary
44	Gunckel, K.L. Wood, M.B.	2015	Science Education	The principle-practical discourse edge: elementary preservice and mentor teachers working together on colearning tasks	USA	Qualitative	29	IBT	Pedagogical	Elementary
45	Gurel, C. Suzuk, E.	2017	Educational Sciences: Theory and Practice	Pre-service physics teachers' argumentation in a model rocketry physics experience	Turkey	Qualitative	21	IBL	Social	Not specified
46	Hacıeminoğlu, E. Yıldız, N,G. Şeker, R.	2022	Sustainability	Factors related to cognitive reasoning of pre-service teachers' science process skills: Role of experiments at home on meaningful learning	Turkey	Mixed Methods	36	IBL	Procedural	Not specified

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
47	Haefner, L.A. Zembal-Saul, C.	2004	International Journal of Science Education	Learning by doing? Prospective elementary teachers' developing understandings of scientific inquiry and science teaching and learning.	USA	Qualitative	11	IBT	Epistemic	Elementary
48	Hakverdi-Can, M. Sönmez, D.	2012	Science Education International	Learning how to design a technology supported inquiry-based learning environment	Turkey	Qualitative	22	IBT	Other	Elementary
49	Hamed, S.; Ezquerra, Á.; Porlán, R.; Rivero, A.	2020	Educational Research	Exploring pre-service primary teachers' progression towards inquiry-based science learning	Spain	Qualitative	347	IBT	Pedagogical	Primary
50	Hayes, M.T.	2002	Journal of Science Teacher Education	Elementary preservice teachers' struggles to define inquiry-based science teaching	USA	Qualitative	22	IBT	Pedagogical, Affective	Elementary
51	Herranen, J. Kousa, P. Fooladi, E. Aksela, M.	2019	International Journal of Science Education	Inquiry as a context-based practice – a case study of pre-service teachers' beliefs and implementation of inquiry in context-based science teaching	Finland	Qualitative	5	IBT	Pedagogical	Lower secondary
52	Hiltunen, M.; Kärkkalinen, S.; Keinonen, T.	2021	Educational Science	Identifying student teachers' inquiry-related questions in biology lessons	Finland	Qualitative	12	IBT	Social, Pedagogical	Primary and secondary
53	Hiltunen, M. Karkkainen, S. Keinonen, T. Hahkioniemi, M. Lehesvuori, S. Tikkanen, P.	2016	Problems of Education in the 21st Century	Primary school student teachers' classroom talk during inquiry-based biology lessons	Finland	Qualitative	5	IBT	Social	Primary
54	Hwang, S. Kim, N. Jeon, S. H. Shim, H. P. Ryu, K. B.	2018	EURASIA Journal of Mathematics Science and Technology Education	Analyzing the growth of a pre-service science teacher community through the lens of cultural historical activity theory: the case of a three-year voluntary science teaching program	Korea	Qualitative	12	IBT	Pedagogical	Not specified

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
55	Inel-Ekici, D.; Ekici, M.	2021	Asia Pacific Education Review	Mobile inquiry-and inquiry-based science learning in higher education: advantages, challenges, and attitudes	Turkey	Qualitative	80	IBL	Other	Elementary
56	Irwanto Saputro, A.D. Rohaeti, E. Prodjosantoso, A.K.	2019	Eurasian Journal of Educational Research	Using inquiry-based laboratory instruction to improve critical thinking and scientific process skills among preservice elementary teachers	Indonesia	Mixed Methods	43	IBL	Procedural, Other	Elementary
57	Isabelle, A.D. de Groot, C.	2008	Journal of Science Teacher Education	Alternate conceptions of preservice elementary teachers: the Itakura method	USA	Mixed Methods	38	IBL	Conceptual	Elementary
58	Jeenjenkit, U. Magee, P.A. Barman, N. Ruenwongsa, P. Panijpan, B.	2011	International Journal of Learning	An inquiry learning unit for enhancing elementary pre-service teacher understanding of factors affecting chemical reaction rate	USA	Mixed Methods	27	IBL	Conceptual	Elementary
59	Kang, E.J.S. Bianchini, J.A. Kelly, G.J.	2013	Journal of Science Teacher Education	Crossing the border from science student to science teacher: preservice teachers' views and experiences learning to teach inquiry	USA	Qualitative	8	IBT	Pedagogical, Affective	Secondary
60	Kapucu, S.	2016	Journal of Education and Future	Guided inquiry-based electricity experiments: pre-service elementary science teachers' difficulties	Turkey	Mixed Methods	80	IBL	Procedural	Elementary
61	Karea, S. Asrial, A. Kurniawan, D.A. Perdana, R. Pratama, R.A.	2021	Eurasian Journal of Educational Research	Implementing inquiry based ethno-constructivism learning module to improve students' critical thinking skills and attitudes towards cultural values	Indonesia	Quantitative	68	IBL	Other	Elementary
62	Kazempour, M. Amirshokoohi, A.	2013	Journal of Education and Learning	Exploring elementary pre-service teachers' experiences and learning outcomes in a revised inquiry-based science lesson: an action research	USA	Qualitative	22	IBL	Conceptual, Affective	Elementary
63	Kim, B.S.	2010	International Journal of Learning	Integration of service-learning into elementary science teaching methods courses	USA	Qualitative	41	IBT	Affective	Elementary

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
64	Kinyota, M.; Rwimo, B.S.	2022	African Journal of Reasearch in Mathematics, Science and Technology Education	Developing student teachers' conceptions of the nature of science: an assessment of a pre-service science teacher programme in Tanzania	Tanzania	Quantitative	346	IBL	Epistemic	Not specified
65	Kiran, D.	2022	International Journal of Science Education	Examining the efficacy change of preservice science teachers: does an inquiry-based laboratory instruction make a difference? A mixed method study.	Turkey	Mixed Methods	52	IBL	Affective	Elementary
66	Krämer, P. Nessler, S.H. Schlüter, K.	2015	Research in Science & Technological Education	Teacher students' dilemmas when teaching science through inquiry	Germany	Qualitative	24	IBT	Pedagogical	Secondary
67	Kukkonen, J. Dillon, P. Kärkkäinen, S. Hartikainen-Ahia, A. Keinonen, T.	2016	Education and Information Technologies	Pre-service teachers' experiences of scaffolded learning in science through a computer supported collaborative inquiry	Finland	Quantitative	114	IBL	Conceptual, Other	Not specified
68	Lee, C.K. Shea, M.	2016	Science Education International	An analysis of pre-service elementary teachers' understanding of inquiry-based science teaching	USA	Mixed Methods	54	IBT	Epistemic, Procedural, Affective	Elementary
69	Leonard, J. Barnes-Johnson, J. Dantley, S.J. Kimber, C.	2011	Urban Review: Issues and Ideas in Public Education	Teaching science inquiry in urban contexts: the role of elementary preservice teachers' beliefs	USA	Mixed Methods	13	IBT	Affective	Elementary
70	Leonard, J. Boakes, N. Moore, C.M.	2009	Journal of Elementary Science Education	Conducting science inquiry in primary classrooms: case studies of two preservice teachers' inquiry-based practices	USA	Qualitative	12	IBT	Conceptual, Pedagogical	Primary
71	Lotter, C. Singer, J. Godley, J.	2009	Journal of Science Teacher Education	The influence of repeated teaching and reflection on preservice teachers' views of inquiry and nature of science	USA	Qualitative	9	IBT	Epistemic, Pedagogical	Secondary

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
72	Luera, G.R. Moyer, R.H. Everett, S.A.	2005	Journal of Elementary Science Education	What type and level of science content knowledge of elementary education students affect their ability to construct an inquiry-based science lesson?	USA	Quantitative	234	IBT	Conceptual	Elementary
73	Lustick, D.	2009	Journal of Science Teacher Education	The failure of inquiry: preparing science teachers with an authentic investigation	USA	Mixed Methods	15	IBL	Procedural, Affective	Secondary
74	Ma, A. van der Flier-Keller, E. Zandvliet, D. Cameron, K.	2021	Journal of Geoscience education	Merging earth science into an environmental education course for K-12 teachers: Is it successful?	Canada	Mixed Methods	51	IBT	Affective	Secondary
75	Magee, P.A Flessner, R.	2012	Science Education International	Collaborating to improve inquiry-based teaching in elementary science and mathematics methods courses	USA	Qualitative	49	IBT	Pedagogical	Elementary
76	McCullagh, J.; Doherty, A.	2021	Education 3–13	A coteaching model for developing pre-service teachers' practice and confidence in teaching primary science through inquiry	Ireland	Qualitative	36	IBT	Pedagogical	Primary
77	McDonald, S. Grimes, P. Doughty, L. Finlayson, O. McLoughlin, E. van Kampen, P.	2019	Journal of Science Teacher Education	A workshop approach to developing the professional pedagogical vision of Irish secondary preservice science teachers	Ireland	Qualitative	18	IBT	Pedagogical	Secondary
78	Meyer, D. Meyer, A.A. Nabb, K. Connell, M. Avery, L.	2013	Research in Science Education	A theoretical and empirical exploration of intrinsic problems in designing inquiry activities	USA	Qualitative	4	IBT	Pedagogical	Not specified
79	Morrison, J.A.	2008	Journal of Science Teacher Education	Individual inquiry investigations in an elementary science methods course	USA	Qualitative	70	IBL	Epistemic, Procedural, Affective	Elementary

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
80	Munoz-Franco, G.; Criado, A.M.; García-Carmona, A.	2020	Research in Science Education	Investigating image formation with a camera obscura: a study in initial primary science teacher education	Spain	Qualitative	104	IBL	Conceptual	Primary
81	Namdar, B.	2018	Research in Science & Technological Education	Teaching global climate change to pre-service middle school teachers through inquiry activities	Turkey	Quantitative	102	IBL	Conceptual, Affective	Middle
82	Nawanidbumrung, W. Samiphak, Ss Inoue, N.	2022	Science Education International	The impact of pre-service teachers' pedagogical beliefs on teaching science as inquiry: A silent antagonist for effective inquiry-based science lessons	Thailand	Qualitative	6	IBT	Pedagogical, Affective	Secondary
83	Nesmith, S. Ditmore, E. Scott, L. Zhu, T.	2017	Electronic Journal of Science Education	'This is More About a Book Than About Science!' Preservice teachers' perceptions towards using literacy strategies in inquiry-based science lessons	USA	Qualitative	64	IBT	Pedagogical	Elementary
84	Nhlengethwa, K.B.; Govender, N.; Sibanda, D.	2020	Journal of Baltic Science Education	Final-year pre-service primary school teachers' understanding of inquiry-based science teaching	Eswatini	Qualitative	34	IBT	Pedagogical	Primary
85	Nhlengethwa, K.B.; Govender, N.; Sibanda, D.	2021	Education 3–13	Primary school pre-service teachers' enactment of inquiry-based science teaching	Eswatini	Qualitative	6	IBT	Pedagogical	Primary
86	Nivalainen, V. Asikainen, M. Hirvonen, P.	2013	Journal of Science Teacher Education	Open guided inquiry laboratory in physics teacher education	Finland	Qualitative	32	IBT	Procedural, Conceptual, Affective	Upper secondary
87	Nugent, G. Toland, M. Levy, R. Kunz, G. Harwood, D. Green, D. Kitts, K.	2012	Journal of Science Teacher Education	The impact of an inquiry-based geoscience field course on pre-service teachers	USA	Mixed Methods	62	IBL	Procedural, Conceptual, Affective	Not specified

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
88	Oh, P.S.	2011	Science Education	Characteristics of abductive inquiry in earth science: an undergraduate case study	Korea	Qualitative	5	IBL	Procedural	Secondary
89	Okulu, H.Z. Ünver, A.O.	2018	International Education Studies	The process of facilitating knowledge acquisition and retention: an inquiry into magnetic poles with challenging questions	Turkey	Quantitative	65	IBL	Conceptual	Primary
90	Otto, C. Everett, S. Moyer, R. Zitzewitz, P.	2012	International Journal of Science & Mathematics Education	Using a state teacher certification test to assess an inquiry-based science education program	USA	Quantitative	1003	IBL	Conceptual	Elementary
91	Ozdem, Y. Ertepinar, H. Cakiroglu, J. Erduran, S.	2013	International Journal of Science Education	The nature of pre-service science teachers' argumentation in inquiry-oriented laboratory context	Turkey	Qualitative	35	IBL	Social	Elementary
92	Ozgelen, S. Yilmaz-Tuzun, O. Hanuscin, D.	2013	Research in Science Education	Exploring the development of preservice science teachers' views on the nature of science in inquiry-based laboratory instruction	Turkey	Qualitative	52	IBL	Epistemic	Elementary
93	Papaevripidou, M. Irakleous, M. Zacharia, Z.C.	2017	Science Education International	Using teachers' inquiry-oriented curriculum materials as a means to examine their pedagogical design capacity and pedagogical content knowledge for inquiry-basedlearning	Cyprus	Qualitative	44	IBT	Pedagogical	Elementary
94	Park, J. Chang, J. Park, J. Yoon, H.G.	2022	International Journal of Science Education	Features of and representational strategies in instructional videos for primary science classes	South Korea	Mixed Methods	16	IBT	Procedural, Pedagogical, Other	Primary
95	Pérez, B.C.	2022	Research in Science Education	Epistemic criteria considered by pre-service teachers for assessing the quality of a scientific investigation about friction force	Spain	Qualitative	71	IBL	Epistemic	Primary
96	Pérez, B.C. Díaz-Moreno, N.	2021	EURASIA Journal of Mathematics, Science and Technology Education	Promoting pre-service primary teachers' development of NOSI through specific immersion and reflection	Spain	Qualitative	40	IBL	Epistemic	Primary

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
97	Pilitsis, V. Duncan, R.	2012	Journal of Science Teacher Education	Changes in belief orientations of preservice teachers and their relation to inquiry activities	USA	Qualitative	13	IBL	Affective	Secondary
98	Plummer, J.D. Ozcelik, A.T.	2015	Science Education	Preservice teachers developing coherent inquiry investigations in elementary astronomy	USA	Mixed Methods	30	IBT	Procedural, Conceptual	Elementary
99	Plummer, J.D. Zahm, V.M. Rice, R.	2010	Journal of Science Teacher Education	Inquiry and astronomy: preservice teachers' investigations of celestial motion	USA	Qualitative	18	IBL	Conceptual	Elementary
100	Prayogi, S.; Verawati, N.N.S. P.	2020	Educational, Cultural and Psychological Studies	The effect of conflict cognitive strategy in inquiry-based learning on preservice teachers' critical thinking ability	Indonesia	Qualitative	18	IBL	Other	Not specified
101	Qablan, A. Al-Ruz, J.A. Theodora, D. Al-Momani, I.	2009	International Journal of Teaching and Learning in Higher Education	'I Know It's so Good, but I Prefer Not to Use It' An interpretive investigation of Jordanian preservice elementary teachers' perspectives about learning biology through inquiry	Jordan	Qualitative	11	IBT	Affective	Elementary
102	Qablan, A.M DeBaz, T.	2015	Teacher Development	Facilitating elementary science teachers' implementation of inquiry-based science teaching	Jordan	Qualitative	15	IBT	Procedural, Affective	Elementary
103	Rees, C. Pardo, R. Parker, J.	2013	Journal of Science Teacher Education	Steps to opening scientific inquiry: pre-service teachers' practicum experiences with a new support framework	Canada	Qualitative	4	IBT	Procedural, Affective	Elementary
104	Richardson, G.M. Liang, L.L.	2008	Journal of Elementary Science Education	The use of inquiry in the development of preservice teacher efficacy in mathematics and science	USA	Quantitative	321	IBL	Affective	Elementary
105	Richardson, G.M. Liang, L.L. Wake, D.G.	2014	Applied Environmental Education and Communication	Examining the durability of environmental education self-efficacy beliefs in preservice teaching	USA	Mixed Methods	33	IBT	Affective	Elementary
106	Riegle-Crumb, C. Morton, K. Moore, C. Chimonidou, A. Labrake, C. Kopp, S.	2015	Science Education	Do inquiring minds have positive attitudes? The science education of preservice elementary teachers	USA	Quantitative	501	IBL	Affective	Elementary

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
107	Rohaeti, E.; Prodjosantooso, A.K.; Irwanto	2020	Journal of Baltic Science Education	Research-oriented collaborative inquiry learning model: improving students' scientific attitudes in general chemistry	Indonesia	Quantitative	64	IBL	Affective	Not specified
108	Salter, I.Y. Atkins, L.J.	2013	Science Education	What students say versus what they do regarding scientific inquiry	USA	Mixed Methods	74	IBL	Epistemic, Procedural	Elementary
109	Sanger, M. J.	2007	Journal of Chemical Education	The effects of inquiry-based instruction on elementary teaching majors' chemistry content knowledge	USA	Qualitative	32	IBL	Conceptual	Elementary
110	Sanger, M. J.	2008	Journal of Chemical Education	How does inquiry-based instruction affect teaching majors' views about teaching and learning science?	USA	Qualitative	40	IBL	Affective	Elementary
111	Saribas, D.	2015	Anthropologist	Pre-service elementary teachers' preferences and competencies in relation to inquiry-based instruction and high quality questions	Turkey	Qualitative	63	IBT	Procedural, Affective	Elementary
112	Schmidt, M. Fulton, L.	2017	Journal of Computers in Mathematics & Science Teaching	Lessons learned from creation of an exemplary STEM unit for elementary pre-service teachers: a case study	USA	Qualitative	35	IBL	Conceptual, Affective, Other	Elementary
113	Schwarz, C.V. Gwekwerere, Y. N.	2007	Science Education	Using a guided inquiry and modelling instructional framework (EIMA) to support preservice K-8 science teaching	USA	Qualitative	24	IBT	Procedural, Pedagogical	Elementary and middle
114	Sen, C. Vekli, G.S.	2016	Universal Journal of Educational Research	The impact of inquiry based instruction on science process skills and self-efficacy perceptions of pre-service science teachers at a university level biology laboratory	Turkey	Mixed Methods	24	IBL	Procedural, Affective	Primary
115	Seung, E. Park, S. Jung, J.	2014	Research in Science Education	Exploring preservice elementary teachers' understanding of the essential features of inquiry-based science teaching using evidence-based reflection	USA	Qualitative	7	IBT	Procedural	Elementary
116	Shively, C.T. Yerrick, R.	2014	Research in Learning Technology	A case for examining pre-service teacher preparation for inquiry teaching science with technology	USA	Qualitative	12	IBT	Procedural, Other	Not specified
117	Smolleck, L.A. Yoder, E.P.	2008	School Science & Mathematics	Further development and validation of the teaching science as inquiry (TSI) instrument	USA	Quantitative	116	IBT	Affective	Elementary

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
118	Soprano, K. Yang, L.	2013	International Journal of Science & Mathematics Education	Inquiring into my science teaching through action research – a case study on one pre-service teacher's inquiry-based science teaching and self-efficacy	USA	Qualitative	21	IBT	Affective	Elementary
119	Soulios, I. Psillos, D.	2016	International Journal of Science Education	Enhancing student teachers' epistemological beliefs about models and conceptual understanding through a model-based inquiry process	Greece	Qualitative	16	IBL	Epistemic, Conceptual	Primary
120	Syer, C. A. Chichekian, T. Shore, B. M. Aulls, M. W.	2013	Instructional Science	Learning 'to do' and learning 'about' inquiry at the same time: different outcomes in valuing the importance of various intellectual tasks in planning, enacting, and evaluating an inquiry curriculum	Canada	Quantitative	166	IBT	Procedural	Elementary
121	Tatar, N.	2012	Journal of Baltic Science Education	Inquiry-based science laboratories: an analysis of preservice teachers' beliefs about learning science through inquiry and their performances	Turkey	Qualitative	2	IBL	Procedural, Affective	Primary
122	Tessier, J.	2010	Journal of College Science Teaching	An inquiry-based biology laboratory improves preservice elementary teachers' attitudes about science	USA	Quantitative	109	IBL	Affective	Elementary
123	Thompson, S. Lotter, C. Fann, X. Taylor, L.	2016	Journal of Science Teacher Education	Enhancing elementary pre-service teachers' plant processes conceptions	USA	Mixed Methods	243	IBL	Conceptual	Elementary
124	Ucar, S. Trundle, K.C.	2011	Computers & Education	Conducting guided inquiry in science classes using authentic, archived, web-based data	Turkey and USA	Mixed Methods	96	IBL	Conceptual	Elementary
125	Ucar, S. Trundle, K.C. Krissek, L.	2011	Research in Science Education	Inquiry-based instruction with archived, online data: an intervention study with preservice teachers	Turkey and USA	Mixed Methods	79	IBL	Conceptual	Elementary
126	Valente, B. Maurício, P. Faria, C.	2022	Science & Education	The influence of real-context scientific activities on preservice elementary teachers' thinking and practice of nature of science and scientific inquiry	Portugal	Qualitative	4	IBT	Epistemic, Pedagogical	Elementary
127	Valls-Bautista, C.; Solé-Llussá, A.; Casanoves, M.	2021	Higher Education, Skills and Work-Based Learning	Pre-service teachers' acquistion of scientific knowledge and scientific skills through inquiry-based laboratory activity	Spain	Mixed Methods	82	IBL	Procedural, Conceptual, Affective	Not specified

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
128	Varma, T.	2011	Global Education Journal	Elementary pre-service teachers' personal science pedagogy concept development and confidence to teach science	USA	Qualitative	40	IBT	Procedural, Affective	Elementary
129	Varma, T. Volkmann, M. Hanuscin, D.	2009	Journal of Elementary Science Education	Preservice elementary teachers' perceptions of their understanding of inquiry and inquiry-based science pedagogy: influence of an elementary science education methods course and a science field experience	USA	Qualitative	40	IBT	Procedural	Elementary
130	Verawati, N.; Hikmawati, H; Prayogi, S.	2020	International Journal of Emergiing Technology in Learning	The effectiveness of inquiry learning models intervened by reflective processes to promote critical thinking ability in terms of cognitive style	Indonesia	Quantitative	24	IBL	Other	Not specified
131	Wang, H.H. Wilson, K. VanRooy, W. Lin, H.S.	2022	Research in Science Education	Pre-service primary teachers' competencies in asking and conducting researchable science questions using fair testing	Australia	Quantitative	38	IBL	Epistemic, Procedural, Affective	Primary
132	Wang, J.	2020	International Journal of Science and Mathematics Education	Compare inquiry-based pedagogical instruction with direct instruction for pre-service science teacher education	USA	Mixed Methods	131	IBT	Conceptual, Pedagogical, Affective	Not specified
133	Wang, J. Sneed, S.	2019	Journal of Science Teacher Education	Exploring the design of scaffolding pedagogical instruction for elementary preservice teacher education	USA	Quantitative	85	IBT	Procedural, Affective	Elementary
134	Weld, J. Funk, L.	2005	Journal of Science Teacher Education	'I'm Not the Science Type': effect of an inquiry biology content course on preservice elementary teachers' intentions about teaching science	USA	Mixed Methods	61	IBL	Procedural, Conceptual, Affective	Elementary
135	Yakar, Z. Baykara, H.	2014	EURASIA Journal of Mathematics, Science & Technology Education	Inquiry-based laboratory practices in a science teacher training program	Turkey	Quantitative	36	IBL	Procedural, Affective, Other	Not specified
136	Yerrick, R.K. Ambrose, R. Schiller, J.	2008	Electronic Journal of Science Education	Ascribing legitimacy: pre-service teachers construction of science teaching expertise in multiple communities	USA	Qualitative	12	IBT	Pedagogical	Elementary

(*Continued*)

(Continued).

No.	Author	Year	Journal	Title	Location of the study	Methods	N=	IBL or IBT	Domain	Level in science teacher education
137	Yoon, H.-G. Joung, Y.J. Kim, M.	2012	Research in Science Education	The challenges of science inquiry teaching for pre-service teachers in elementary classrooms: difficulties on and under the scene	South Korea	Qualitative	16	IBT	Pedagogical	Elementary
138	Yoon, H.-G. Kim, M. Kim, B.S. Joung, Y.J. Park, Y.-S.	2013	EURASIA Journal of Mathematics, Science & Technology Education	Pre-service teachers' views of inquiry teaching and their responses to teacher educators' feedback on teaching practice	South Korea	Qualitative	15	IBT	Procedural, Pedagogical	Elementary
139	Zhou, G. Xu, J.	2017	International Journal of Education in Mathematics, Science and Technology	Microteaching lesson study: an approach to prepare teacher candidates to teach science through inquiry	Canada	Qualitative	73	IBT	Procedural, Pedagogical	Not specified
140	Zulfiani, Z. Herlanti, Y.	2018	Journal of Turkish Science Education	Scientific inquiry perception and ability of pre-service teachers	Indonesia	Mixed Methods	90	IBT	Procedural	Not specified
141	Önder, F. Senyigit, C. Silay, I.	2018	European Journal of Physics	Effect of an inquiry-based learning method on students' misconceptions about charging of conducting and insulating bodies	Turkey	Mixed Methods	19	IBL	Conceptual	Not specified
142	Özer, F.; Saribas, D.	2022	Science & Education	Exploring pre-service science teachers' understanding of scientific inquiry and scientific practices through a laboratory course	Turkey	Mixed Methods	39	IBT	Epistemic	Secondary